NASA Technical Memorandum 86755

USAAVSCOM Technical Report 85-A-11

A Simulation Investigation of Scout/Attack Helicopter Directional Control Requirements for Hover and Low-Speed Tasks

Courtland C. Bivens and Joseph G. Guercio

March 1987

NASA
National Aeronautics and
Space Administration

US ARMY
AVIATION
SYSTEMS COMMAND
AVIATION RESEARCH AND
TECHNOLOGY ACTIVITY

NASA Technical Memorandum 86755
USAAVSCOM Technical Report 85-A-11

A Simulation Investigation of Scout/Attack Helicopter Directional Control Requirements for Hover and Low-Speed Tasks

Courtland C. Bivens, Aeroflightdynamics Directorate, U.S. Army Aviation Research and Technology Activity, Ames Research Center, Moffett Field, California

Joseph G. Guercio, Ames Research Center, Moffett Field, California

March 1987

NASA
National Aeronautics and Space Administration

Ames Research Center
Moffett Field, California 94035

US ARMY
AVIATION
SYSTEMS COMMAND

AVIATION RESEARCH AND TECHNOLOGY ACTIVITY
MOFFETT FIELD, CA 94305 1099

TABLE OF CONTENTS

SYMBOLS

AHIP	Army helicopter improvement program
a	rotor blade slope-of-the-lift curve
C_g	torque-to-power turbine, ft-lb
C_{T_s}	main rotor coefficient of thrust
CGI	computer generated imagery
C-H	Cooper-Harper pilot ratings
f	fuselage
FOV	field of view
g	acceleration due to gravity, ft/sec^2
HUD	head-up display
h	height above the ground, ft
I_{E+R}	combined power turbine/rotor inertia, slug-ft^2
IGE	in-ground-effect
Kc	airframe transfer functions
K_f	Munk correction factor
Kp	pilot transfer functions
K_z	spanwise station, fraction of semispan
L	length, ft
L_u, L_v, L_w	scale lengths for u, v, w, respectively, ft
LHX	light helicopter family
mr	main rotor
N_g	gas generator speed, percent
N_r	angular rate damping in yaw, 1/sec

N_v	weathercock stability, $\frac{rad/sec^2}{ft/sec}$
N_{δ_p}	directional control sensitivity, $\frac{rad/sec^2}{in.}$
NOE	nap of the Earth
OGE	out of ground effect
OVC	outside visual cues
PMD	panel-mounted display
PR	pilot rating
Q_r	torque required, ft-lb
Q_s	torque supplied ft-lb
R	main rotor radius, ft
rms	root mean square
rpm	revolutions per minute
S	area, ft^2
s	Laplace operator
tr	tail rotor
u,v,w	airspeed components along body x,y,z axes, respectively, ft/sec
u_g,v_g,w_g	disturbance velocity along the x,y,z axes, respectively, ft/sec
U_o	simulated wind speed knots, ft/sec
$\bar{V}$	volume coefficient
V	steady wind speed, ft sec
vt	vertical tail
W	maximum gross weight, lb
$\bar{X}^2$	mean square
Y_r	side force due to yaw velocity · 1/m, sec^{-1}

Y_v	side force per unit lateral velocity · 1/m, ft/(rad-sec)
α	level of significance
Δ	small change from trim condition
$\delta_a, \delta_b, \delta_c, \delta_p$	controller positions, longitudinal cyclic, lateral cyclic, collective pedal, respectively, in.
μ	tip speed ratio
ζ	damping ratio
σ	main rotor solidity ratio
σ_T	rms aircraft heading response to turbulence with no pilot inputs
$\sigma_u, \sigma_v, \sigma_w$	rms intensity of u_g, v_g, w_g
$\Phi_{(\ )}$	turbulence spectrum for u_g, v_g, w_g, $\frac{ft/sec^2}{rad/sec}$
ϕ, θ, ψ	Euler roll, pitch, yaw angles, respectively, rad
ψ_o	aircraft heading out of the wind direction, deg
$\dot{\psi}$	yaw rate, rad/sec
$\ddot{\psi}$	yaw acceleration, rad/sec^2
$\bar{\omega}_s$	velocity along tail rotor shaft axis

A SIMULATION INVESTIGATION OF SCOUT/ATTACK HELICOPTER DIRECTIONAL CONTROL REQUIREMENTS FOR HOVER AND LOW-SPEED TASKS

Courtland C. Bivens
Aeroflightdynamics Directorate
U.S. Army Aviation Research and Technology Activity
Ames Research Center

and

Joseph G. Guercio
Ames Research Center

SUMMARY

A piloted simulator experiment was conducted to investigate directional axis handling qualities requirements for low-speed (≤40 knots) and hover tasks performed by a Scout/Attack (SCAT) helicopter. Included in the investigation were the directional characteristics of various candidate light helicopter family configurations. Also, the experiment focused on conventional single main/tail rotor configurations of the OH-58 series aircraft, where the first-order yaw-axis dynamic effects that contributed to the loss of tail rotor control were modeled. Two types of yaw stability and control augmentation systems were implemented: one consisting of washed-out yaw rate feedback and shaped control input, the other a yaw rate command, heading-hold system. Five pilots flew 22 configurations under various wind conditions. Cooper-Harper handling quality ratings were used as the primary measure of merit of each configuration. Piloting performance measures were used as backup information only since it was observed during the experiment that each pilot displayed a remarkable ability to compensate for degraded handling qualities. The results of the experiment indicate that rotorcraft configurations with high-directional gust sensitivity require greater minimum yaw damping to maintain satisfactory handling qualities during nap-of-the-Earth (NOE) flying tasks. It was also determined that both yaw damping and control response are critical handling qualities parameters in performing the air-to-air target acquisition and tracking task. The lack of substantial yaw damping and larger values of gust sensitivity increased the possibility of loss of directional control at low airspeeds for the single main/tail rotor configurations. Task performance measures do have a predictive validity with reference to task success, but such measures cannot be used as a substitute for pilot ratings in evaluating vehicle handling qualities. The pilot tends to accommodate his output to a wide range of variations in control parameters without permitting degradation of vehicle performance. This accommodation is accomplished by a shift of effort and attention to the control task.

INTRODUCTION

To reduce the possibility of detection and engagement from sophisticated enemy weapon systems, future battlefield nap-of-the-Earth (NOE) helicopter operations will involve extremely agile flightpath control at very low altitudes (below treetop level where possible) to take maximum advantage of the cover afforded by trees and the terrain features. To accomplish this more demanding operational scenario, new piloting techniques and vehicle flight control requirements have been rapidly evolving over the past few years. The anticipated role of the Advanced Scout/Attack (SCAT) helicopter has been expanded to include the use of sophisticated on-board systems such as Target Acquisition and Display (TADS), multipurpose missile systems, holographic sighting, speech-command auditory/display systems, advanced digital and optical control systems, and multifunctional displays. The advanced SCAT helicopter operating out of unprepared landing zones will provide close combat support, reconnaissance, security, target acquisition/designation, fire support, command, and control (along with self-defense) under day, night, and adverse weather conditions and in all intensities of warfare (fig. 1). To be effective in the high-threat combat environment it is necessary that the advanced SCAT helicopter be exceptionally agile and possess excellent handling qualities to perform the required NOE

Figure 1.- SCAT combat operations.

mission. Excellent NOE handling qualities will allow the pilot to concentrate on aspects outside the cockpit or engage in battlefield management tasks. The pilot's workload in this flight regime is very high and the effect of the helicopter's handling qualities or performance will be significant (ref. 1).

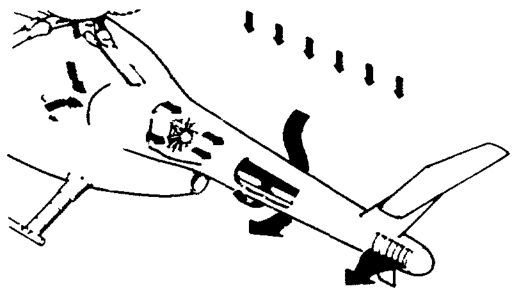
General NOE flight does not in itself impose the need for stringent yaw control requirements (refs. 2-4). Good response characteristics are desirable to enable the pilot, who is quite busy, to devote less attention to yaw control. When the aircraft is used to aim weapons or sights, yaw control becomes very important. Each type of weapon/sight and tactical situation, however, will require different maneuvers which may result in differing requirements for each situation. No analysis of various weapons and maneuvers was available in reference 2, but, by using common maneuvers, some tentative requirements were set up (42°/sec for maximum yaw rates in conducting rapid pedal reversals with a response time-constant <0.25 sec). High control power is required, but this alone is not enough. Precision of yaw control also requires ample damping (ref. 5). Sufficiently high control power, as indicated by a specified heading change within a certain time interval, will provide the capability for achieving the desired result. However, if the rate-response time-constant is long, the pilot will use an excessive number of control motions with a resulting over-and-under shooting as he "hunts" for the desired heading.

It can also be seen that a pilot's evaluation of the yaw control characteristics of the helicopter will not only depend on the maneuver which he must perform with the machine, but also on the severity of the wind and the gust sensitivity of the helicopter. In reference 6, it was concluded that the existing wind conditions, to a major extent, dictated the results of the evaluation. Wind levels and the gust sensitivity of the vehicle must be considered in the definition of acceptable control characteristics and the interpretation of related test data. If a vertical takeoff and landing (VTOL) aircraft has high-yaw gust sensitivity, which is the case for a single main rotor helicopter, then precision flight during gusty wind conditions would be difficult. It would be desirable to increase the damping and thereby reduce the pilot effort; however, if the inherent damping is increased by changing the dimensional characteristics of the tail rotor, the gust sensitivity would also be increased and there would be no reduction in pilot effort. A machine with no tail rotor and with low "weathercock" stability, for instance, will not require the large yaw control moments to execute high-speed sideward flight or to maneuver during high-wind conditions. Also, that machine will not be subjected to large yaw disturbances caused by wind gusts. Reference 4 concludes that the definition of yaw control criteria, and the interpretation of related test results, must involve considerations of the gust sensitivity of the aircraft and the operational wind condition.

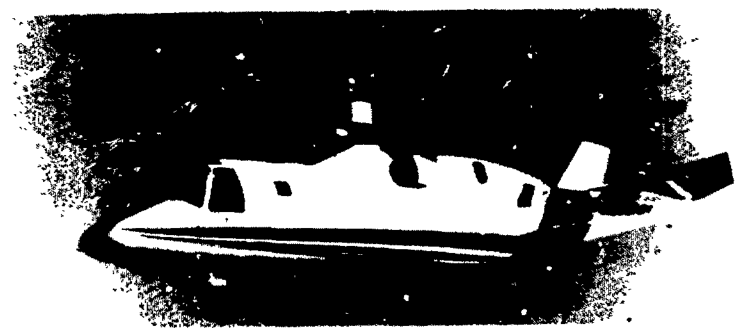
The latest generation of rotary wing aircraft has a wide range of inherent gust sensitivity. The XH-59A advancing blade concept (ABC) develops yaw control through differential collective of the two rotor systems. The XV-15 Tilt Rotor develops yaw control via differential cyclic inputs; the Hughes No Tail Rotor (NOTAR) concept uses a circular control tail boom, a direct jet thruster, and a cambered vertical fin to provide anti-torque and directional control forces (fig. 2). These

DIRECTIONAL STABILITY (N_v) = CONTRIBUTIONS OF FUSELAGE + VERTICAL TAIL + TAIL ROTOR + SHAFT TILT

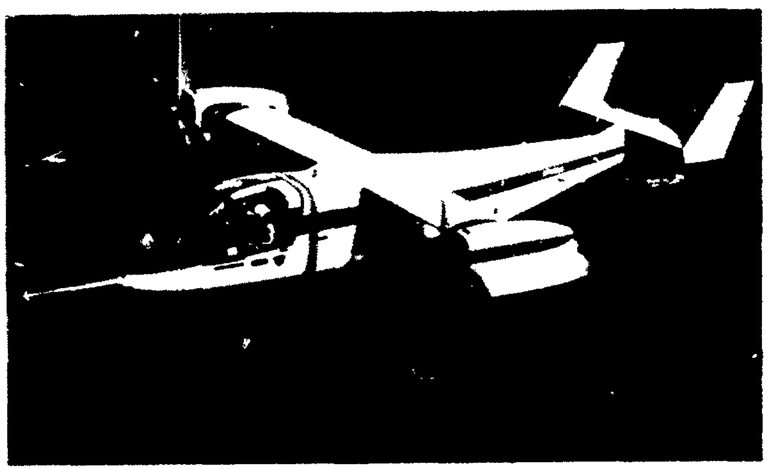
YAW DAMPING (N_r) = CONTRIBUTIONS OF VERTICAL TAIL + TAIL ROTOR + MAIN ROTOR + AUGMENTATION SYSTEMS



NOTAR



ABC



TILT ROTOR

AHIP

Figure 2.- Aircraft design implications.

configurations are all possible contenders for the Army's light helicopter family (LHX). References 7-9 suggest that additional analysis and data are needed to determine the effect of vehicle mission and directional control requirements for varied helicopter configurations. Some data were obtained in reference 6 showing that minimum acceptable damping was a function of N_v. The investigation (conducted in the presence of a simulated 15-knot wind and a simulated turbulence signal equivalent to 8.9 ft/sec rms gust intensity) shows a very distinct linear variation between minimum damping ratios and weathercock stability (N_v) for hover flight at the 3-1/2 and 6-1/2 pilot rating boundaries (see fig. 3). Also concluded was that the inclusion of the controlled, simulated turbulence was extremely important.

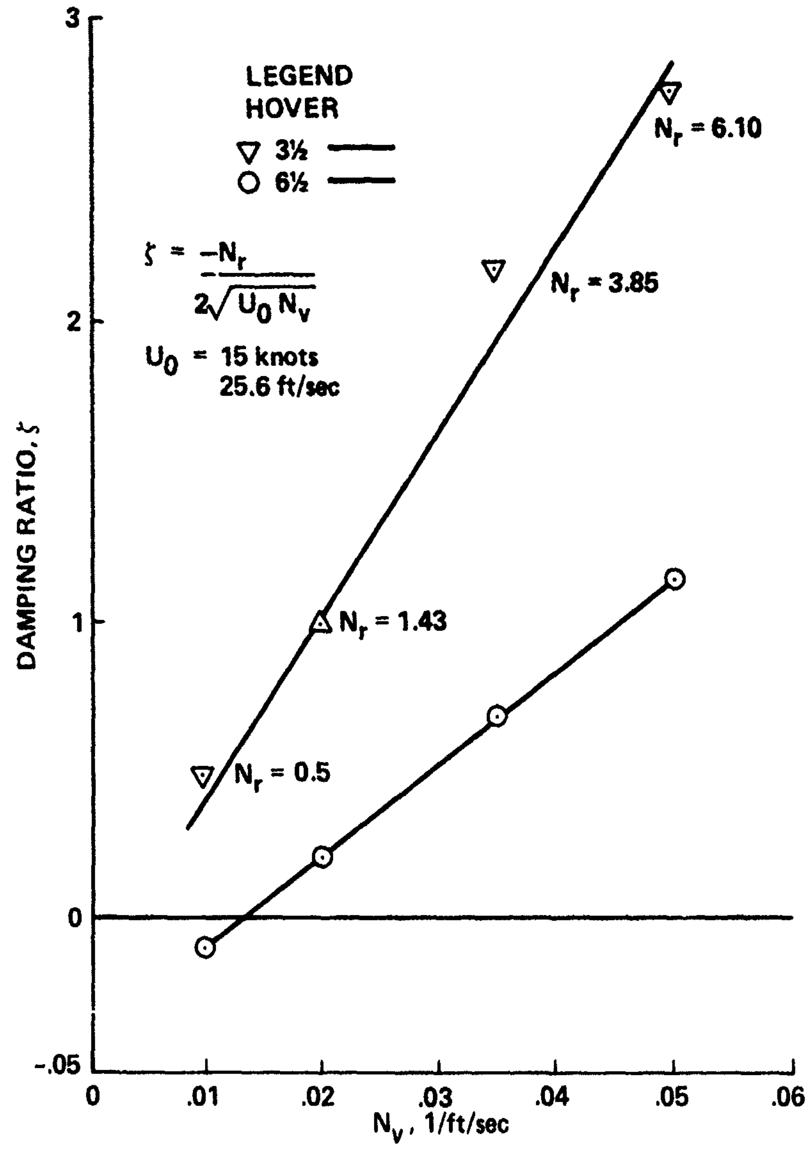


Figure 3.- Minimum damping ratio versus N_v.

Current Requirements for Helicopter and VTOL Aircraft

There has been considerable disagreement with respect to minimum acceptable yaw damping and sensitivity levels in hover. Figures 4 and 5 indicate some of these requirements including some current aircraft values. It can readily be seen that these requirements are not dependent upon aircraft configuration (other than gross weight) or mission task. MIL-F-83300 and MIL-H-8501A do address environmental factors but again their overall correlation to aircraft configuration and maneuvering task is absent. MIL-F-83300 states "that with the wind from the most critical

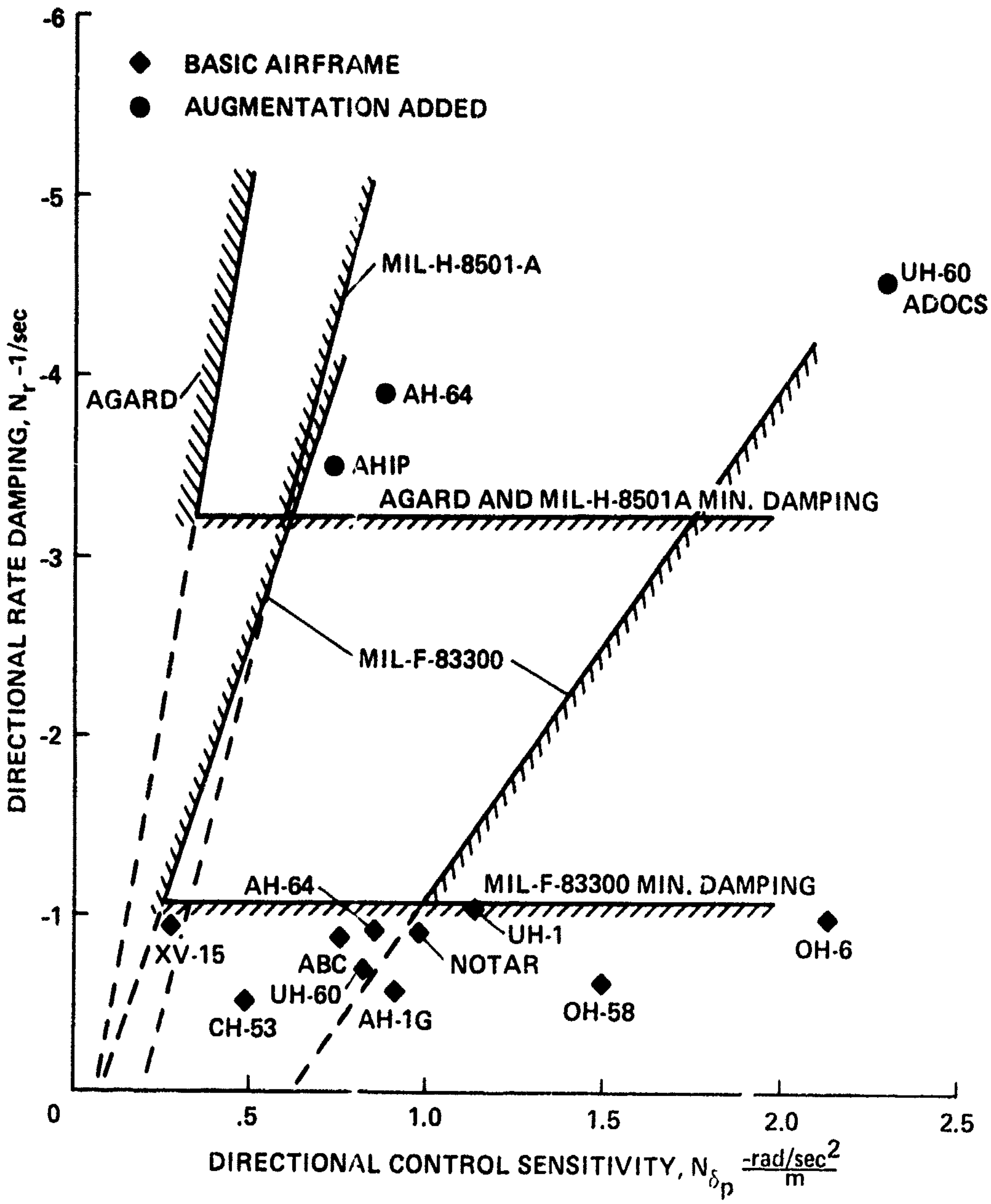


Figure 4.- Comparison of handling qualities criteria and various aircraft configurations.

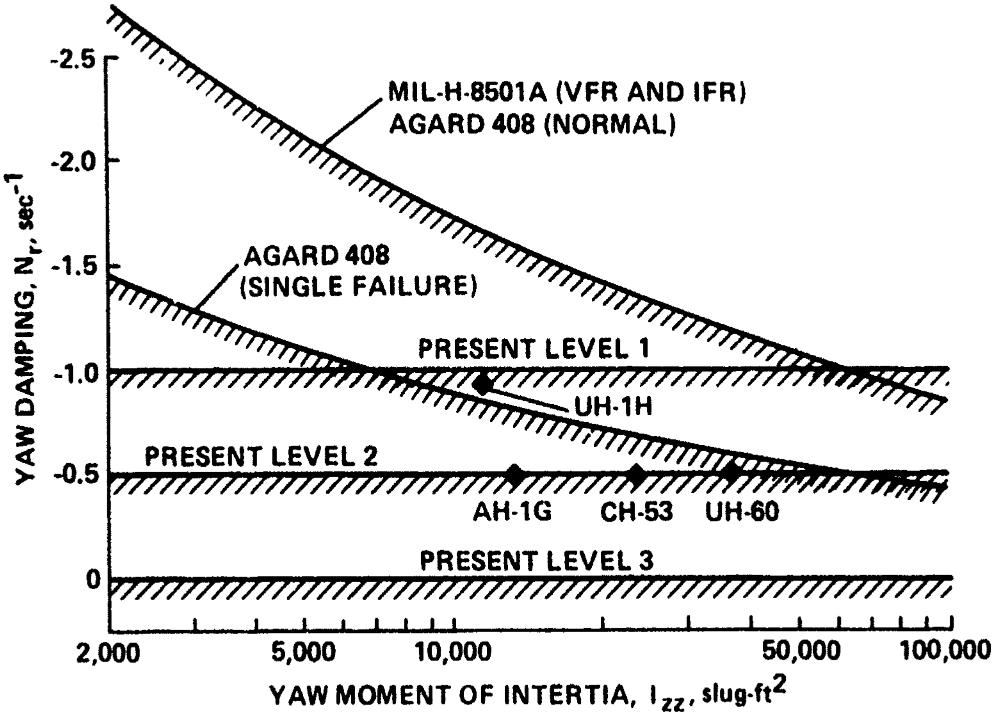


Figure 5.- Directional damping requirements in hover.

directions relative to the aircraft, control remaining shall be such that simultaneous abrupt applications of yaw control produce at least 6 degrees within one second." Data from previous experiments (refs. 10-12) help substantiate this criterion, but the control power also depends on the type of control system, the disturbances encountered, and the particular maneuvers.

MIL-F-83300 also states that while hovering at zero airspeed, the yaw mode shall be stable and the time constant shall not exceed 1.0 sec (for Level 1). The choice of minimum acceptable yaw damping appears to be a function of N_v, although at this time there is no satisfactory manner of stating a requirement to ensure mutual compatability of gust response and control response characteristics (refs. 13-15). MIL-H-8501A (ref. 16) states "That it shall be possible to execute a complete turn in each direction while hovering over a given spot at the maximum overload gross weight or at takeoff power (in and out of ground effect) in a wind of at least 35 knots. To ensure adequate margin of control during these maneuvers, sufficient control shall remain at the most critical azimuth relative to the wind, in order that, when starting at zero yawing velocity at this angle, the rapid application of full directional control in the critical direction results in a corresponding yaw displacement of at least $110/\sqrt[3]{W + 1000}$ degrees in the first second." Also the sensitivity shall be considered excessive if the yaw displacement is greater than 50° in the first second following a sudden pedal displacement of 1 in. from trim while hovering at the lightest normal service loading. This specification is very definitive for hovering over a spot but it does not address low speed yaw

requirements for maneuvers such as: quick stop and turn into wind (refs. 3 and 4); rapid pedal reversals for area fire (ref. 2); and acquisition and tracking of air targets. It does seem to provide maximum and minimum limits for the overall controllability of the vehicle.

Yaw Weathercock Stability

The directional stability N_v is a measure of the tendency of the vehicle to align itself in sideslip, like a weathercock, with the relative wind. The problem that evolves for helicopter designers is that the aircraft must operate in both hovering and forward flight regimes. A compromise between providing adequate forward flight directional stability and ensuring low gust sensitivity in hover is required. The principal contributions are from the tail rotor, fuselage, and vertical tail. Using slender body theory, the Munk correction factor (K_f) defined in reference 17, and a volume coefficient based on an equivalent (inside view) body of revolution, reference 17 estimates the fuselage contribution as:

$$\Delta_f N_v = \frac{-g}{\Omega R(2C_{T_s}/a\sigma)} \frac{K_f \bar{V}_f}{R(K_z/R)^2} \frac{2\mu}{a_{mr}\sigma} \tag{1}$$

where $\bar{V}_f$ volume coefficient = $vol_f/\pi R^3$. It is generally an unstable contribution that is more or less proportional to forward speed. The vertical tail lends a stable contribution that, according to reference 17, may be evaluated by:

$$\Delta_{vt} N_v = \frac{g}{\Omega R(2C_{Ts}/a\sigma)} \frac{(a_{tR}/2)\bar{V}_{vt}}{R(K_z/R)^2} \frac{2\mu}{a_{mr}\sigma} \tag{2}$$

where

$$\bar{V}_{vt} \equiv \frac{S_{vt}L_{vt}}{\pi R^3}$$

It is very much proportional to forward speed. The major contribution to directional stability for conventional configurations comes from the tail rotor. Its contribution to yawing moment due to sideslip is estimated in reference 17 as:

$$\Delta_{tr} N_v = \frac{g}{\Omega R(2C_{Ts})/a\sigma} \times \frac{\bar{V}_{tr}(L_{tr}/R)}{R(K_z/R)^2} \times \left[\frac{2}{a_{MR}\sigma} \frac{\partial C_{Ts}}{\partial \bar{\omega}_s}\right]_{tr} \tag{3}$$

where

$$\bar{V}_{tr} = \frac{\sigma_{tr}\Omega_{tr}R_{tr}^3}{\sigma\Omega R^3}$$

The tail rotor term is, of course, stabilizing and approximately independent of forward speed. The sum of these components (eqs. (1)-(3)) becomes the total directional stability

$$N_v = \Delta_f N_v + \Delta_{vt} N_v + \Delta_{tr} N_v \tag{4}$$

(There are other factors such as rotorshaft tilt. Depending on their importance in the aircraft configuration, they can be included or neglected.) By inspecting each component at a hover and low airspeed, it can be readily observed that the tail rotor effect is extremely dominant. And with any small changes in inflow along the tail rotor shaft axis, the entire moment is correspondingly affected. At higher steady state airspeeds this factor helps stability, since the direction of travel is into the relative wind. But at a hover in turbulence, when one may wish to maintain a hover position (not only directly into the wind, but with the wind in any quadrant), this factor can cause problems. This effect manifests itself in pilots' objections based on increased workload due to the disturbances caused by the turbulence (refs. 10-12).

In surveying various configurations, it is readily apparent that most single main rotor helicopters of conventional configuration have higher values of N_v (due to the tail rotor contribution) in hover and low speed than configurations which do not depend on a tail rotor for directional stability and control (table 1).

TABLE 1.- VALUES OF N_V (V < 30 KNOTS) FOR VARIOUS AIRCRAFT

Conventional helicopters (data extracted from ref. 18)		Other VTOL configurations		
OH6	= 0.0251	X-22A	= 0.005	
BO-105	= .0166	XC-142A	= .00037	
AH1G	= .0119	X-19	= .0005	
UH1H	= .0211	XV-5A	= .002	
CH53	= .0103	XV-15	= .0017	
UH60	= .012	NOTAR	= .003	
AHIP	= .022	ABC	= .002	
AH-64	= .017	CH-47	= .0025	

With increasing airspeed, the stable vertical fin contribution and the generally unstable contribution of the fuselage increase for both conventional and nonconventional configurations.

Control Response Characteristics

In addition to vehicle dynamics, the pilot's opinion of a vehicle's flying qualities is also influenced by control sensitivity. The improper selection of sensitivity can degrade the flying qualities of an otherwise satisfactory vehicle to an unacceptable level. In this investigation $N_{\delta p}$ was made a dependent variable since there has been considerable work already conducted to optimize this parameter. The bulk of the data supporting this approach comes from references 10-12 where the relationship between control sensitivity and damping in the yaw axis was explored.

Task Requirements and Environmental Factors

For piloted flight simulations, it was concluded in references 10-12 that increasing weathercock stability, in the presence of turbulence, requires significantly larger values of damping. Also, the minimum directional damping levels are a function of the task performed. It was also a critical part of this simulation to precisely define evaluation tasks for generating mission-oriented handling qualities data. For this investigation these tasks were defined as (utilizing ref. 19):

1) NOE flight

2) NOE deceleration

3) IGE hover

4) OGE hover

5) Air-to-air target acquisition at hover

In order to design aircraft of various configurations with optimum handling qualities, reference 20 strongly recommends the use of piloted simulation where the aircraft physical characteristics and geometry can be varied under different environmental conditions for various NOE maneuvers. The data from these efforts could then be used toward eventual airworthiness qualification of advanced aircraft and provide a data base for all subsequent specifications. For the present time, reference 8 states that for cases of atmospheric disturbances (such as discrete gust, wind shear, and turbulence) the contractor shall choose the conditions subject to the approval of the procuring authority.

Some requirements (as in MIL-F-8501A) can be demonstrated in flight. In reference 21 it was shown that the addition of turbulence had a marked effect on pilot opinion and performance. Satisfactory handling qualities could only be achieved with higher levels of damping to wash out the effects of the turbulence. If VTOL aircraft are going to be utilized in a real-world situation, this environmental factor should always be included as a requirement.

Flightpath Management

The ability of a rotorcraft pilot to perform the flightpath management function is determined by the handling qualities of the vehicle: "Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role" (ref. 1). Handling qualities are determined not only by the stability and control characteristics of the vehicle, but also by the displays and controls which define the pilot-vehicle interface, the environmental characteristics, and the performance requirements for the task (refs 22-24) (fig. 6).

In developing yaw axis handling qualities criteria which are relevant for different candidate rotorcraft, this experimental investigation attempted to find some meaningful relationship between aircraft stability and control configurations, the control task, aircraft environment and required task performance measures. The ingenuity of a contractor's technical solution to meet military performance standards should not be limited by outdated specifications which may not lead to an aircraft design optimized for the mission.

EXPERIMENTAL DESIGN

Yawing Equations of Motion and Fxperimental Variables

An approximate yawing equation of motion for a helicopter in hover is presented in reference 10 as:

$$\dot{\psi} = N_{\delta p} \cdot \delta_p + N_r \cdot \dot{\psi} + N_v \cdot v + N_v \cdot v_g \qquad (5)$$

For this simplified analysis the lateral velocity, v, of equation (5) may be generated only as a result of a crosswind component of the mean wind U_o. This relation is $v = -U_o \sin \psi$, where ψ is the yaw angle measured from the direction of the simulated wind. Equation (5) may then be written:

$$\ddot{\psi} = N_{\delta p} \cdot \delta_p + N_r \cdot \dot{\psi} - U_o N_v \sin \psi + N_v \cdot v_g \qquad (6)$$

For small disturbances from a trimmed flight condition at an angle ψ_o to the simulated wind, equation (6) becomes

$$\Delta\ddot{\psi} = N_{\delta p} \cdot (\Delta\delta_p) + N_r \cdot (\Delta\dot{\psi}) - U_o N_v \cos \psi_o(\Delta\psi) + N_v \cdot v_g)$$
$$+ (N_{\delta p} \cdot \delta_{p_o} - U_o N_v \sin \psi_o) \qquad (7)$$

where $\Delta\psi$ and $\Delta\delta_p$ are the disturbance yaw angle and pedal displacement from the trimmed condition of ψ_o and δ_{p_o}, since δ_{p_o} is the pedal input required to trim at ψ_o to the wind

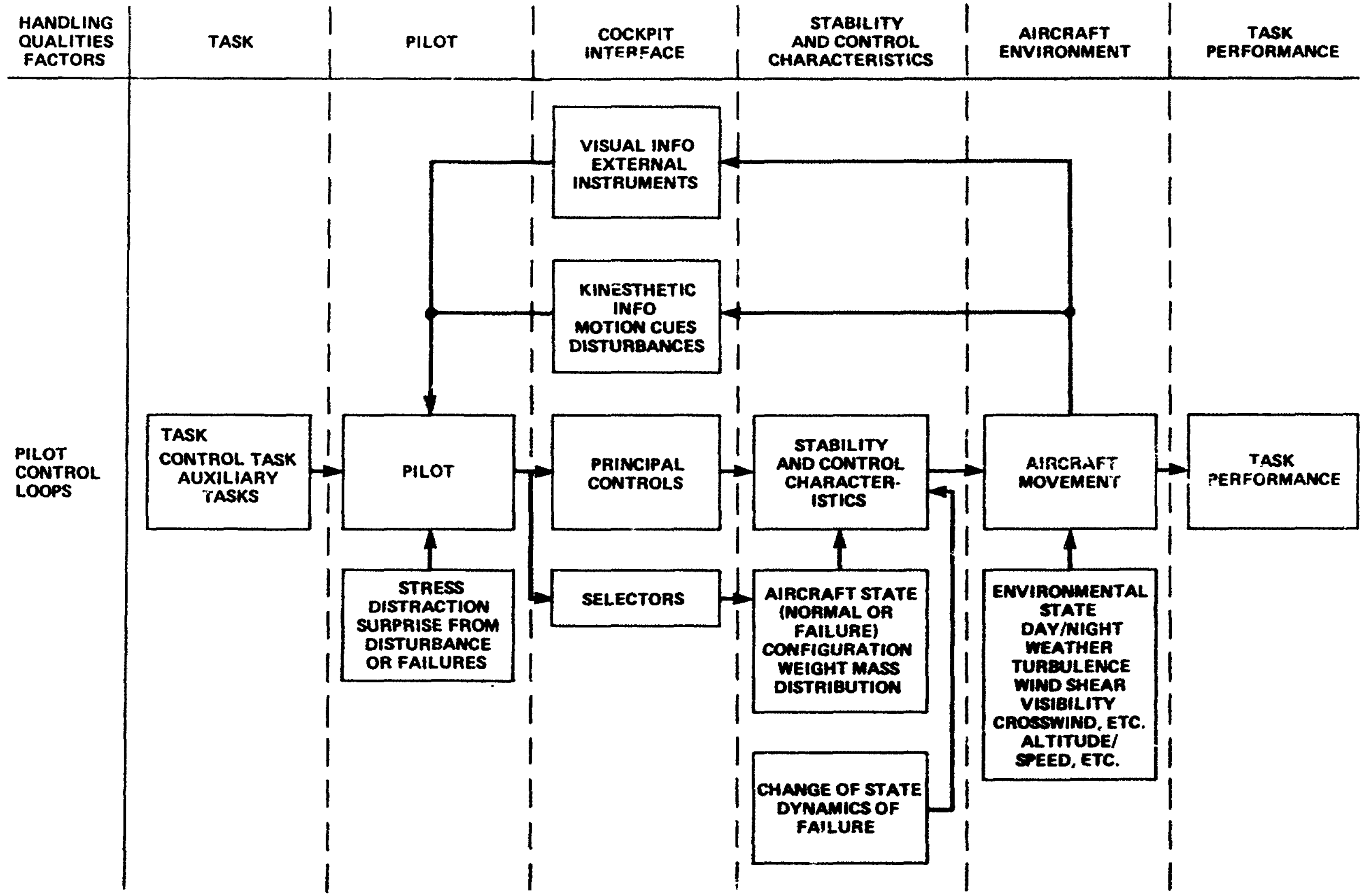


Figure 6.- Elements of control loop that influence handling qualities (ref. 32).

$$N_{\delta_p} \cdot \delta_{p_o} - U_o N_v \sin \psi_o = 0 \qquad (8)$$

and equation (7) in Laplace notation, becomes

$$(S^2 - N_r S + U_o N_v \cos \psi_o)\Delta\hat{\psi}(S) = N_{\delta_p} \cdot \Delta\hat{\delta}_p(S) + N_v \hat{v}g(S) \qquad (9)$$

The transfer function relating the yaw rate response to pedal input becomes

$$\frac{\dot{\psi}}{\delta_p}(S) = \frac{N_{\delta p} S}{S^2 - N_r S + U_o N_v \cos \psi_o} \qquad (10)$$

The small amplitude directional response is oscillatory with natural frequency $\sqrt{U_o N_v \cos \psi_o}$ and damping ratio $-N_r/(2\sqrt{U_o N_v \cos \psi_o})$. When trimmed into the wind, the frequency is simply $\sqrt{U_o N_v}$; when trimmed cross wind, the directional response becomes that of a simple first-order system

$$\frac{\dot{\psi}}{\delta_p}(S) = \frac{N_{\delta_r}}{S - N_r}$$

and when trimmed down wind, the mode is statically unstable, having a divergent root of

$$\frac{N_r}{2}\left[1 - \sqrt{1 + \frac{U_o N_v}{(N_r/2)^2}}\right]$$

and a convergent root of

$$\frac{N_r}{2}\left[1 + \sqrt{1 + \frac{U_o N_v}{(N_r/2)^2}}\right]$$

Hence, in addition to the wind conditions, the dominant contributors to hover directional stability and control characteristics are $N_{\delta p}$, N_r, and N_v. The derivation of the directional transfer function applicable during translational flight must recognize the contribution made by the lateral translational degree of freedom of the basic helicopter. According to reference 10, the three equations determining the lateral-directional motions of the helicopter (written using the Laplace operator) are

Side force

$$(S - Y_v)\hat{v} - (Y_p S + g)\hat{\phi} + (U - Y_r)\hat{\dot{\psi}} = Y_{\delta_p} \cdot \hat{\delta}_p + Y_{\delta_a} \cdot \hat{\delta}_a \qquad (11)$$

Rolling equation

$$S(S - L_p)\hat{\phi} = L_{\delta_a} \cdot \hat{\delta}_a \tag{12}$$

Yawing equation

$$-N_v \cdot \hat{v} + (S - N_r)\hat{\dot{\psi}} = N_{\delta_p} \cdot \hat{\delta}_p + N_v \cdot \hat{v}_g \tag{13}$$

The side force derivatives are the dimensional derivatives of the helicopter divided by the helicopter mass.

From the above equations ((11)-(13)) the transfer function relating yaw rate to pedal input is

$$\frac{\dot{\psi}}{\delta_p}(S) = \frac{N_{\delta_p}[S - Y_v + (Y_{\delta_p}/N_{\delta_p})N_v)}{S^2 - (N_r + Y_v)S + (N_rY_v - Y_rN_v) + UN_v} \tag{14}$$

The denominator of this expression determines the normal modes of lateral-directional motion and hence the stability characteristics. The dominant parameters for a helicopter in low speed flight are again N_{δ_p}, N_r, and N_v.

The main purpose of this experiment was to investigate the yawing degree of freedom described by the above transfer functions. The effects of weathercock stability and angular rate damping were the independent variables; N_{δ_p} was assigned as the dependent variable to attempt to maintain a near-constant steady state yaw rate response to pedal input. The damping and sensitivity were varied over different ranges of N_v selected. Figure 7 shows the combinations of the various parameters that made up each test configuration. As indicated in figure 7, the ranges of N_v also correspond to different types of LHX candidate aircraft.

Mathematical Model

General- The aircraft equations of motion were represented by the full set of nonlinear gravitational and inertial terms of the equations (appendix A). The aerodynamic forces and moments were represented by reference values and first-order terms of a Taylor-series Expansion about a reference trajectory defined as a function of the total airspeed (ref. 25). The values of the trim, stability, and control parameters for the basic SCAT aircraft were obtained from a generic nonlinear mathematical total force and moment model of a single main rotor helicopter (ARMCOP) (ref. 26) using input source data from the Bell model 406 Army Helicopter Improvement Program (AHIP) (appendix A). The ARMCOP tail rotor is assumed to be a two-bladed teetering rotor; tail rotor flapping, vortex-ring-state dynamics, and adverse fin flow were not modeled. To represent primary nonlinear tail rotor effects, N_r and N_{δ_p} were derived as a function of magnitude and as a direction of the relative wind; this technique produced results which compared very favorably to data obtained

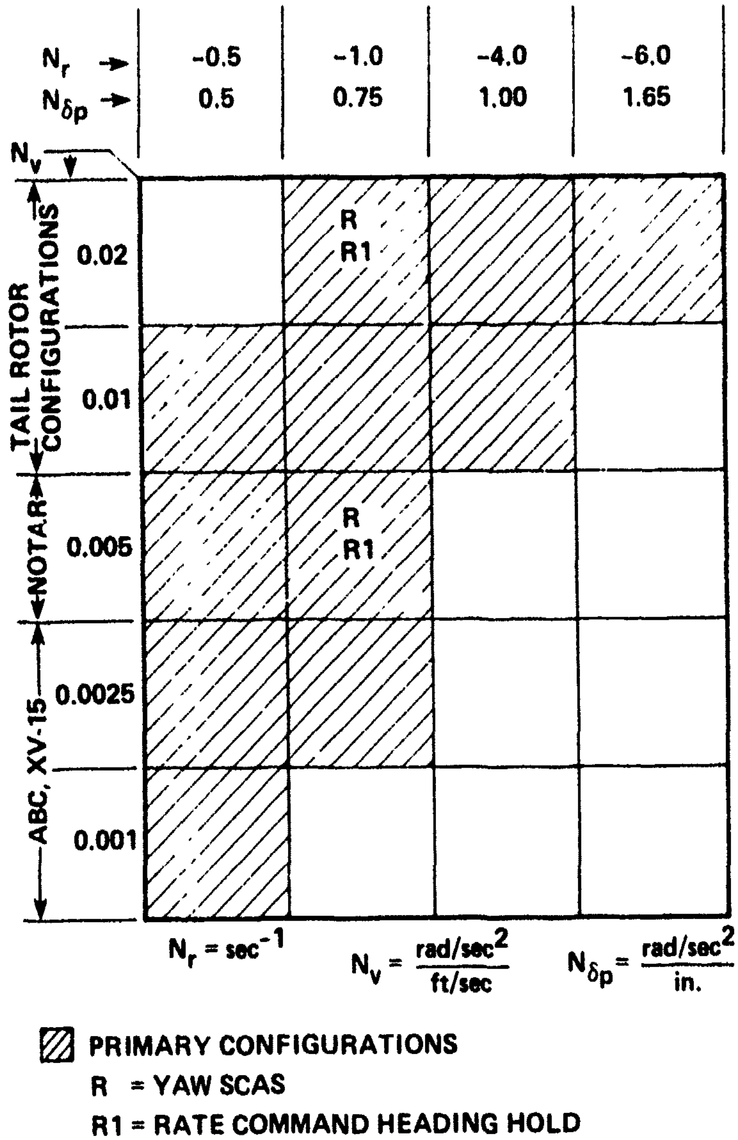


Figure 7.- Experimental matrix.

in reference 27 (fig. 8). Also pedal and collective trim positions utilizing the ARMCOP model exhibited similar trends as compared to wind tunnel and flight test data (ref. 28) (fig. 9).

An engine model was included in the simulation to take into account the effects of variations in rotor rpm on the total yawing moment and heave-axis force. The engine model included a representation of an electronic fuel control system; for a 1-in. change in collective, the rotor rpm exhibited a maximum transient droop of less than 1% (appendix A). Figure 10 illustrates the change in tail rotor pitch and pedal trim conditions for resulting changes in main rotor rpm. In the case of a 1%-rpm droop, the effective change in pedal margin and tail rotor capability to counteract main rotor torque is minimal.

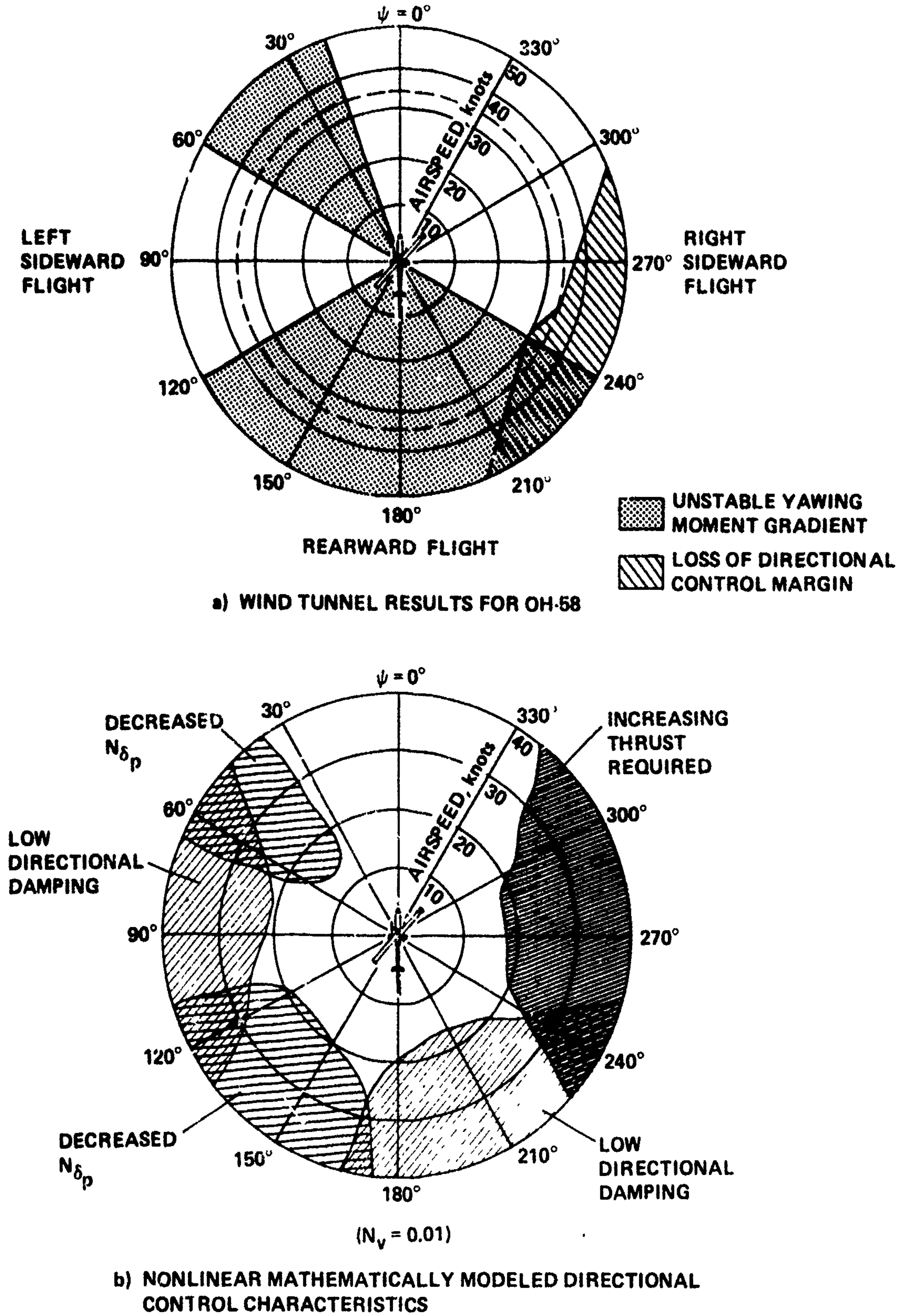


Figure 8.- Comparison of derived directional control characteristics.

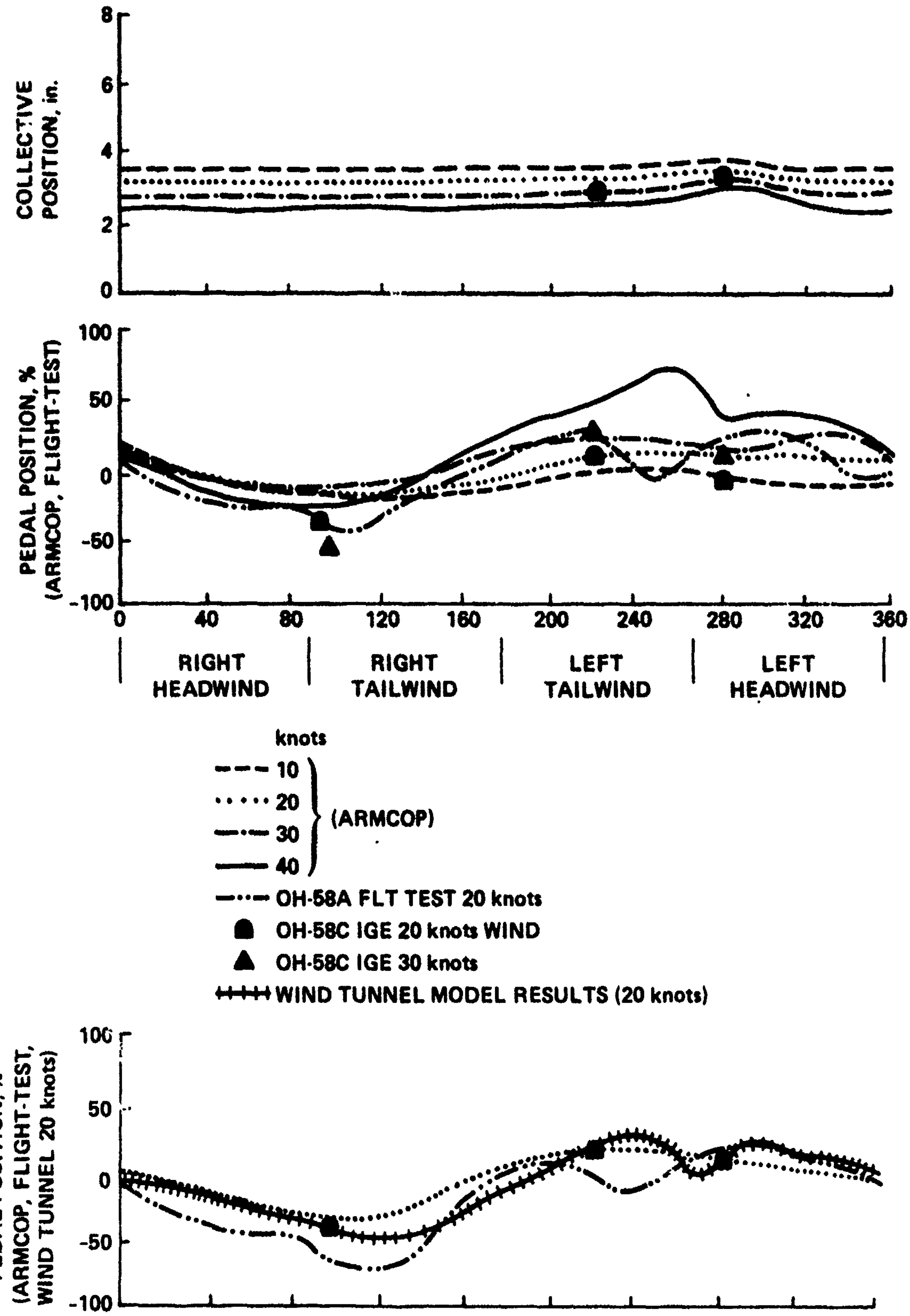


Figure 9.- Comparison of pedal and collective positions for ARMCOP, wind tunnel, and flight test data.

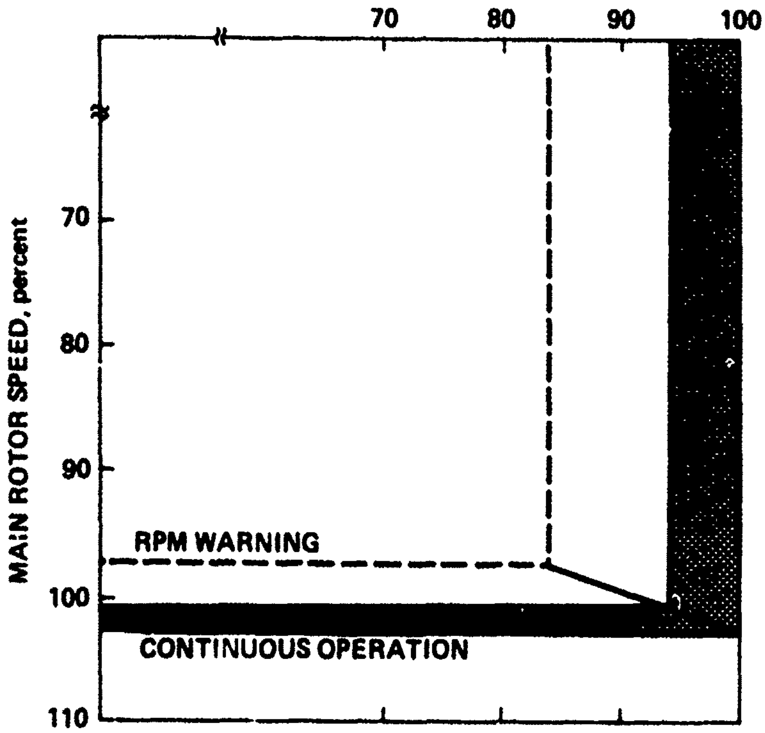


Figure 10.- Main rotor effect on tail rotor capability to counteract rotor torque.

Augmentation- To maintain good handling qualities in the pitch, roll, and heave axes, all configurations included displays and augmentation. The purpose of the added stability and control augmentation was to significantly reduce pilot workload in the pitch, roll, and heave axes so that they would not become dominant factors affecting pilot opinion of performance. The criteria used for the SCAT display and augmentation came from a classification scheme developed by Hoh and Ashkenas in reference 22. They were able to quantify the intuitive idea that the minimum acceptable handling qualities for low speed and hover are strongly dependent on the visibility level and available displays. They proposed an outside visual cues scale that gave a fine-grained quantification of available outside cues (table 2). Computer generated imagery (CGI) systems are limited, when trying to provide a good usable cue environment, due to the reduced field-of-view and lack of detail. After comparing the FOV of the vertical motion simulator CGI display to that of the SCAT (fig. 11), it was subjectively decided that the simulator would, in the worst case, be a 2 on the OVC scale. Applying this number to the maximum allowable visual cues table, to achieve level 1 handling qualities, it is necessary to have at least an attitude (response feedback) system and an integrated flight director (for when position and velocity cues are only adequate).

TABLE 2.- OUTSIDE VISUAL CUE (OVC) SCALE (REF. 22)

QUANTIFICATION OF OUTSIDE VISUAL CUES

	ATTITUDE CUES	POSITION AND VELOCITY CUES	OVC LEVEL
VMC	Easily obtained.	Easily obtained.	1
VMC	Somewhat obscured. Requires full concentration to obtain continuous attitude information.	Easily obtained.	2
Partial IMC	Inadequate in some sectors of the visual field.	Adequate position. Marginal rate cues.	3
Partial IMC	Inadequate over most of visual field.	Position and rate cues are marginal. Rate cues are intermittently unavailable.	4
IMC	Not available	Not available	5

MAXIMUM ALLOWABLE VISUAL CUE LEVELS FOR EACH CATEGORY OF EQUIVALENT SYSTEM RESPONSE

LOWER ORDER EQUIVALENT SYSTEM TYPE		PILOT DISPLAY		
	MIL-F-83300 FLYING QUALITY LEVEL	RAW DATA	MECHANICAL FLIGHT DIRECTOR	INTEGRATED DISPLAY-FLIGHT DIRECTOR PLUS AIRCRAFT VELOCITY INFORMATION
Rate	Level 1	1	2	3
	Level 2	2	4	5
Rate Command Attitude Hold	Level 1	2	3	3
	Level 2	2	5	5
Attitude (response feedback)	Level 1	2	3	3
	Level 2	2	5	5
Attitude (model following)	Level 1	2	4	4
	Level 2	2	5	5
Translational Rate with Attitude	Level 1	3	5	5
	Level 2	3	5	5
Translational Rate with Direct Force Control	Level 1	3	5	5
	Level 2	3	5	5

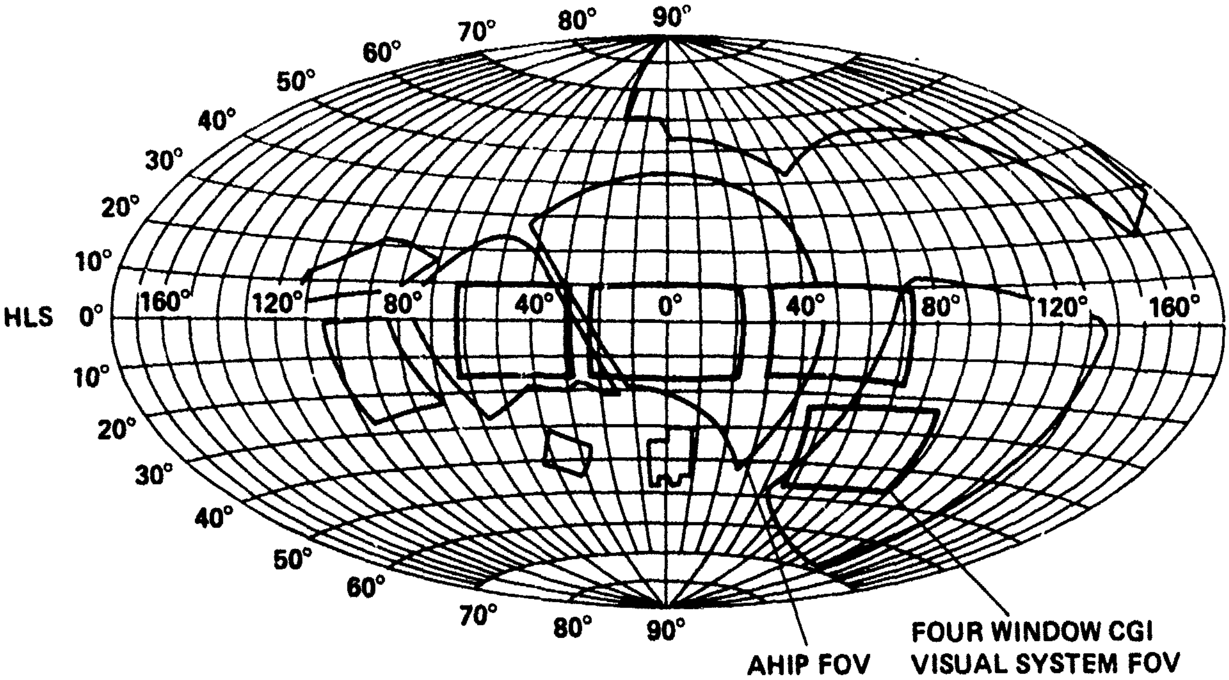


Figure 11.- Pilots' field-of-view comparisons.

The pitch and roll axis augmentation consisted of an inertial velocity command system while the heave axis consisted of a rate-command altitude-hold. The yaw stability and control augmentation systems included two concepts designed for hover and low speed (<40 knots). The actual implementation of these systems for the simulation (refs. 25,29,30) is discussed in appendix B.

The yaw stability and control augmentation systems (SCAS) comprised washed-out yaw rate damping augmentation and control quickening. The rate-command heading-hold included integral-plus-rate feedback and an integral-plus-proportional feed forward to provide steady-state acceleration. A dead zone was included in the integral feed forward paths to prevent drift caused by the integration of inadvertent pilot control inputs (appendix B). The control force characteristics in appendix C were implemented and were the same throughout the experiment.

Turbulence and wind- A meaningful investigation of weathercock stability in hover and slow flight also consisted of including the effects of turbulence and steady wind velocities. The following model from reference 25, based on the MIL-F-8785C Dryden model (ref. 31) was implemented:

Dryden turbulence model

$$u_g = \Phi_{u_g} \cdot \text{(white noise)} - \text{amplitude I}$$

$$v_g = \Phi_{v_g} \cdot \text{(white noise)}$$

$$w_g = \Phi_{w_g} \cdot \text{(white noise)}$$

where

$$\Phi_{u_g} = \sigma_u \sqrt{\frac{2Lu}{\pi V}} \; \frac{1}{1 + (Lu/V)s}$$

$$\Phi_{v_g} = \sigma_v \sqrt{\frac{Lv}{\pi V}} \; \frac{1 + (\sqrt{3}Lv/v)s}{[1 + (Lv/V)s]^2}$$

$$\Phi_{w_g} = \sigma_w \sqrt{\frac{Lw}{\pi V}} \; \frac{1 + (\sqrt{3}Lw/V)s}{[1 + (Lw/V)s]^2}$$

where turbulence "break frequencies" correspond to the values of V/L

Altitude	V/Lw rad/sec	V/Lu = V/Lv rad/sec
20 ft	1.27	0.25
200 ft	.13	.025

The vertical turbulence intensity σ_w was specified as being 10% of the mean wind speed measured at 20 ft above ground level (AGL). The ratio of the horizontal turbulence intensities σ_u and σ_v to the vertical intensity varied as a function of altitude from the value of 1.0 at 1000 ft to 2.0 at zero altitude. The scale lengths required were (from ref. 25):

$$L_w = \begin{cases} h & \text{for } h \geq 20 \text{ ft} \\ 20 & \text{for } h < 20 \text{ ft} \end{cases}$$

$$L_u = L_v \begin{cases} 5h & \text{for } 200 \text{ ft} \geq 20 \text{ ft} \\ 100 & \text{for } h < 20 \text{ ft} \\ 1000 & \text{for } h > 200 \text{ ft} \end{cases}$$

To provide the effects of steady wind and wind shear, the magnitude of the steady wind was specified at two altitudes: 20 ft and 200 ft AGL. Linear interpolation was used to determine mean wind speed between these altitudes. Beyond these altitude extremes the mean wind speed remained constant. Wind direction was specified as a function of altitude in a similar fashion. The wind conditions are defined in table 3.

TABLE 3.- SIMULATED WIND CONDITIONS

	20 ft (AGL)	200 ft (AGL)
LIGHT	19 knots	21 knots
MODERATE	21 knots	26 knots
STRONG	34 knots	45 knots

CONDUCT OF THE EXPERIMENT

In this experiment the task assigned to the pilot included control of the aircraft and associated functions, but it did not include tasks that were indirectly related to control of the aircraft such as navigation and communications. The overall mission was to conduct Scout/Attack operations in an NOE environment. The mission profile consisted of five task segments representative of a typical SCAT mission conducted during the day (ref. 19), specifically:

1) NOE flight

2) Deceleration to a hover

3) Precision hovering turn (in-ground effect)

4) Precision hovering turn (out-of-ground effect)

5) Air-to-air target acquisition and engagement

The profile began at the start point (fig. 12) with the aircraft at 50 ft and 40 knots. After negotiating the canyon course at or below 50 ft AGL, a deceleration maneuver was performed with the aircraft coming to a hover (10 ft AGL) in the center of the hover area pointing to the east. At that time the pilot performed a 180° left turn while maintaining position over the pivot point and at a constant altitude. After stabilizing the aircraft at the 180° point, the pilot turned the aircraft 180° back to the right. He then initiated a vertical climb and unmasked at 75-ft (AGL) altitude while maintaining the eastern orientation and position over the ground. The pilot then again executed a 180° left turn. After completion of the OGE turn, the pilot oriented the aircraft to 120° magnetic to wait for the initiation of the air target. The target (CGI helicopter) was automatically initiated from the simulation control console. The target direction was changed randomly from left to right, and from right to left. The times of the target appearance varied randomly from 2 to 8 sec. This was done to prevent the pilots from anticipating when and where the target would appear. The pilot attempted to acquire and engage the enemy aircraft with an air-to-air missile in the following manner:

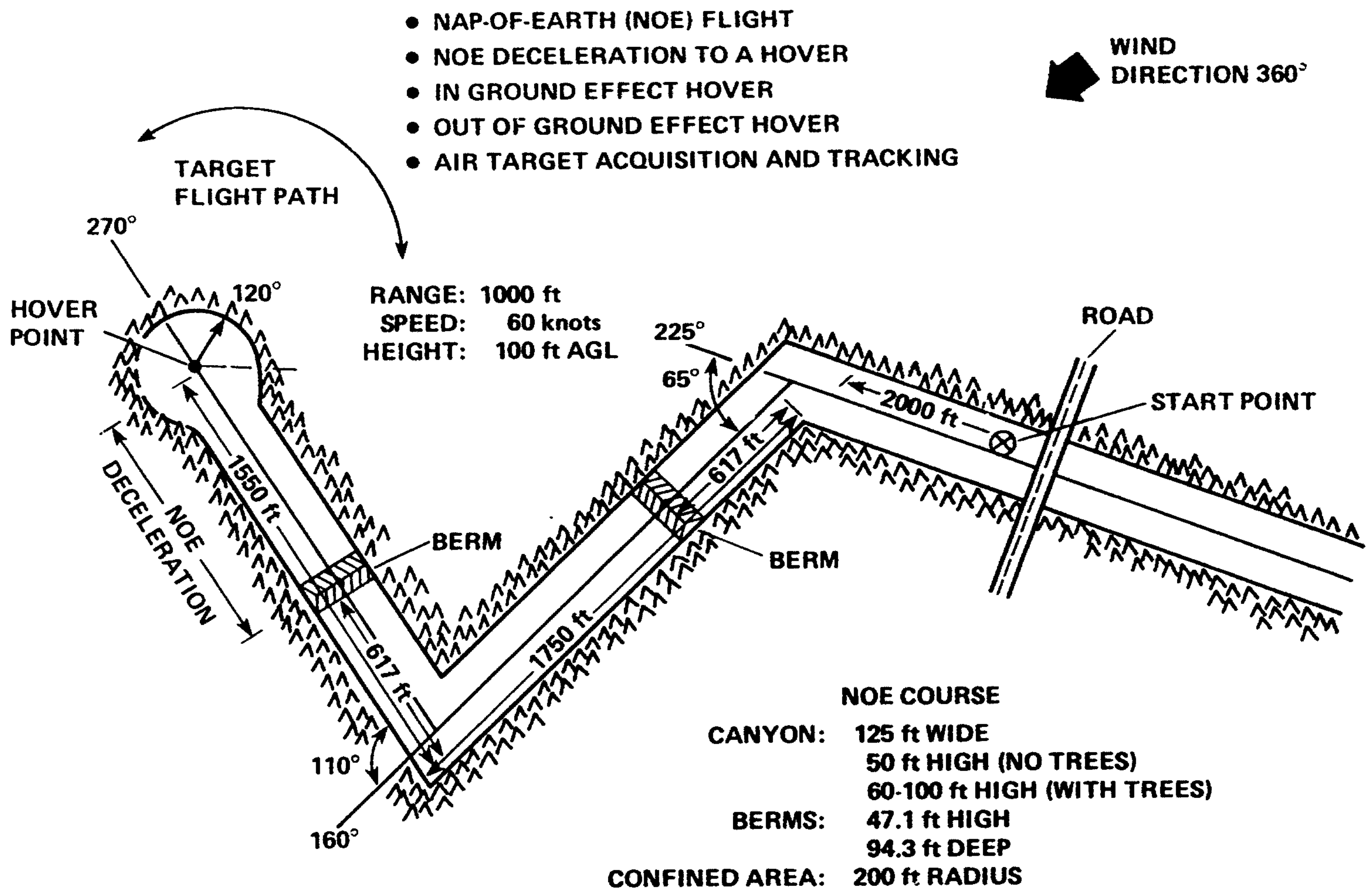


Figure 12.- Nap-of-the-Earth course (CGI data base).

1) Pilot activated fire control symbols on HUD using cyclic switch after detecting target

2) Pilot maneuvered aircraft to align sight pipper on center of gravity of target (±1°)

3) Seeker acquisition tone (1.2 kHz) indicated infrared energy being received. Missile launch constraints box appeared (±6° elevation, ±6° azimuth)

4) After 2 sec of target being inside missile launch constraints a steady 2.5 kHz acquisition tone indicated good track, missile ready

5) Pilot depressed fire trigger, rocket motors ignited, enemy aircraft was destroyed (sound and visual)

Before each pilot started record runs he was given five to eight familiarization runs. These runs were accomplished to give the pilot a good idea what standards were required of him in performing each of the mission tasks. Also, before the first run of each simulation period, the pilot subjects familiarized themselves again with the tasks by reading the pilot instructions (appendix D). The pilots were not informed of the characteristics of the particular configuration under evaluation. At the conclusion of the run, a Cooper-Harper pilot rating (ref. 32) was assigned and general pilot comments regarding the yaw axis handling qualities were elicited.

Each of the test configurations was presented to the pilots in a random order. The orders were divided into three groups: primary, secondary, and yaw augmentation configurations. The method was used so that the interesting configurations were looked at first. This took into account the possibility that, because of such things as simulation schedules, malfunctions, all the test configurations might not be examined. Also, each of the presentation orders was different for each pilot. This was done in order to prevent the effects of learning from benefitting any particular test configuration(s) and generating misleading results. For the target acquisition task, the target direction and target appearance time were randomly assigned. This prevented the pilots from being able to predict where and when each target would appear. Again, this was done to keep the test results from being influenced by an irrelevant variable. An example of a presentation order is illustrated in figure 13.

Five pilots served as evaluation pilots for the experiment:

1) Pilot 1: Army experimental test pilot with 3,400 flight hr, 2,200 of which were in rotary-wing aircraft, 100 hr NOE experience.

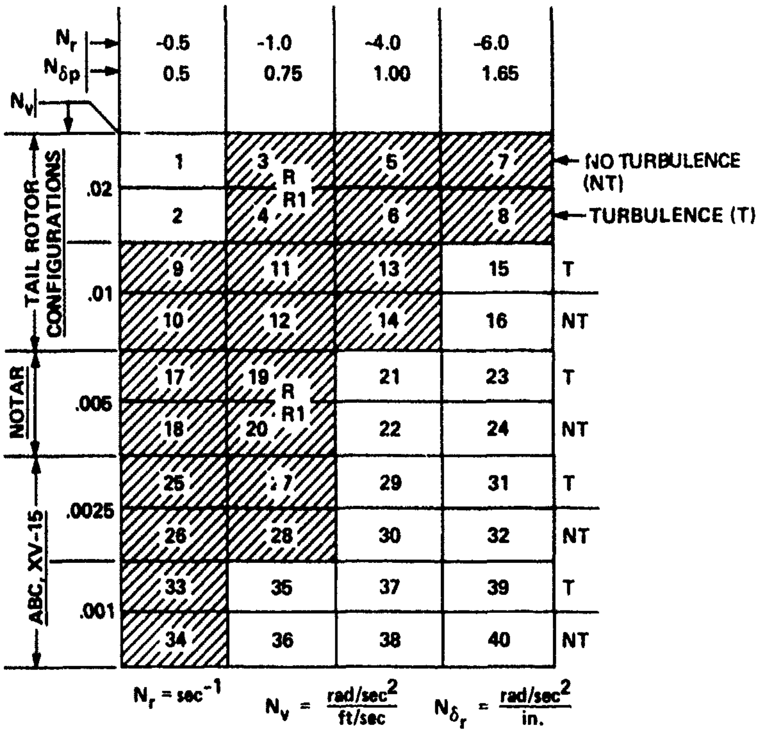
2) Pilot 2: Army experimental test pilot with 3,800 flight hr, 1,700 of which were in rotary-wing aircraft, 100 hr NOE experience.

3) Pilot 3: Civilian experimental test pilot with 5,100 flight hr, 2,900 of which were in rotary-wing aircraft, 500 hr NOE experience.

PILOT 4

RUN NO.	CONFIG.	TARGET DIR[1]	TARGET DELAY[2] (SECS)	
1	4	+	8	PRIMARY CONFIGURATIONS
2	18	+	4	
3	12	+	8	
4	5	–	2	
5	7	+	4	
6	26	+	8	
7	6	–	2	
8	20	–	6	
9	13	–	2	
10	27	–	2	
11	19	–	6	
12	9	–	6	
13	11	+	8	
14	28	–	2	
15	33	+	4	
16	25	+	8	
17	34	+	4	
18	14	–	2	
19	17	+	4	
20	3	+	8	
21	10	–	6	
22	8	+	4	
23	15	+	8	SECONDARY CONFIGURATIONS
24	1	–	6	
25	38	+	4	
26	32	+	8	
27	35	+	2	
28	2	–	6	
29	31	–	8	
30	29	+	6	
31	16	–	8	
32	39	+	6	
33	30	–	6	
34	37	–	4	
35	24	+	4	
36	21	+	2	
37	40	–	6	
38	36	–	2	
39	22	–	2	
40	23	+	4	
41	3 R	+	8	YAW AUGMENTATION CONFIGURATIONS
42	19 R1	–	2	
43	19 R	+	8	
44	3 R1	+	4	

EXPERIMENTAL MATRIX



PRIMARY CONFIGURATIONS
R = YAW SCAS
R1 = RATE COMMAND HEADING HOLD

[1] + → MEANS TARGET FLIES FROM LEFT TO RIGHT
– → MEANS TARGET FLIES FROM RIGHT TO LEFT

[2] DELAY IS FROM SELECTION OF BOB-UP DISPLAY TO START OF TARGET FLIGHT, AND WAS LIMITED TO ONE OF FOUR VALUES

Figure 13.- Typical pilot-subject configuration order.

4) Pilot 4: Army experimental test pilot with 4,700 flight hr, 3,600 of which were in rotary-wing aircraft, 75 hr NOE experience.

5) Pilot 5: Army pilot/engineer with 1,100 flight hr, 1,000 of which were in rotary-wing aircraft, 400 hr NOE experience.

Facility and Cockpit Configuration

This piloted simulation was conducted on the Ames Research Center vertical motion simulator (fig. 14). A four-window, computer-generated-image (CGI) system provided the visual display. Figure 15 shows the view of each of the four windows superimposed on the pilot's field of view in a typical helicopter. The scene shown depicts the NOE canyon course. The rocks and trees on the sides of the canyon wall were used to provide height and attitude cues. The patterning on the canyon walls and floor provided the relative motion cues.

A Sigma 8 computer generated the simulator math model and a PDP 11/40 computer drove the Evans and Sutherland head-up display (HUD) and a 9 in. KRATOS panel-mounted display (PMD). The display format and characteristics are given in appendix A. A conventional helicopter arrangement similar to the OH58D was used with artificial force-feel loaders driving a cyclic stick, a collective stick, and pedals. The cockpit dimensions, control system characteristics, and instrument layout are illustrated in appendix C. A sound system provided aural cues driven by parameters from the mathematical model used in the simulation. Aural cueing was used throughout the simulation for the rotors, air-rush noise, engine/transmission and missile fire control cues necessary for the conduct of the experiment.

Data Acquisition

Along with the pilot ratings and tape recorded pilot comments, real time aircraft state data were collected. Three strip charts were used to record the experimental digital variables. The variables specified are listed in appendix E. Immediate post-run aircraft performance data to include preliminary statistics were provided from a Versatec line printer. The aircraft state and performance data were also recorded on magnetic tape for post-simulator processing and analysis.

RESULTS

Analysis of Experimental Pilot Rating Data

A total of 147 data runs were obtained employing the pilot-subjects. All of the individual pilot ratings, averaged pilot rating data, and pilot comment data for each task are listed in appendixes F and G. A correlation analysis (appendix F) and an analysis of variance were also conducted on the ratings of the primary test configurations, which enabled indexing pilot sensitivity to configuration and task changes and examining significant interaction between the primary variables.

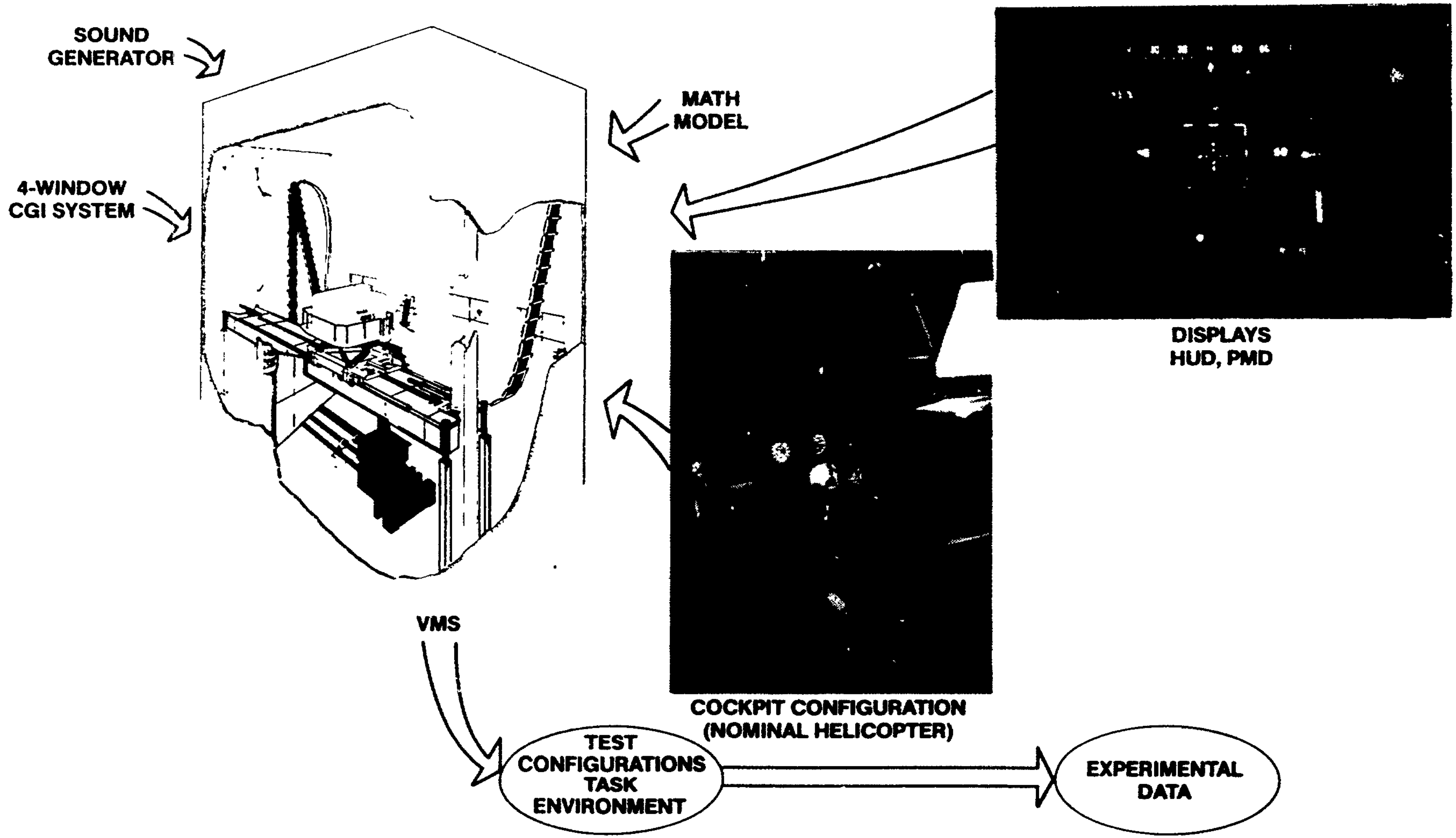


Figure 14.- Experimental facility.

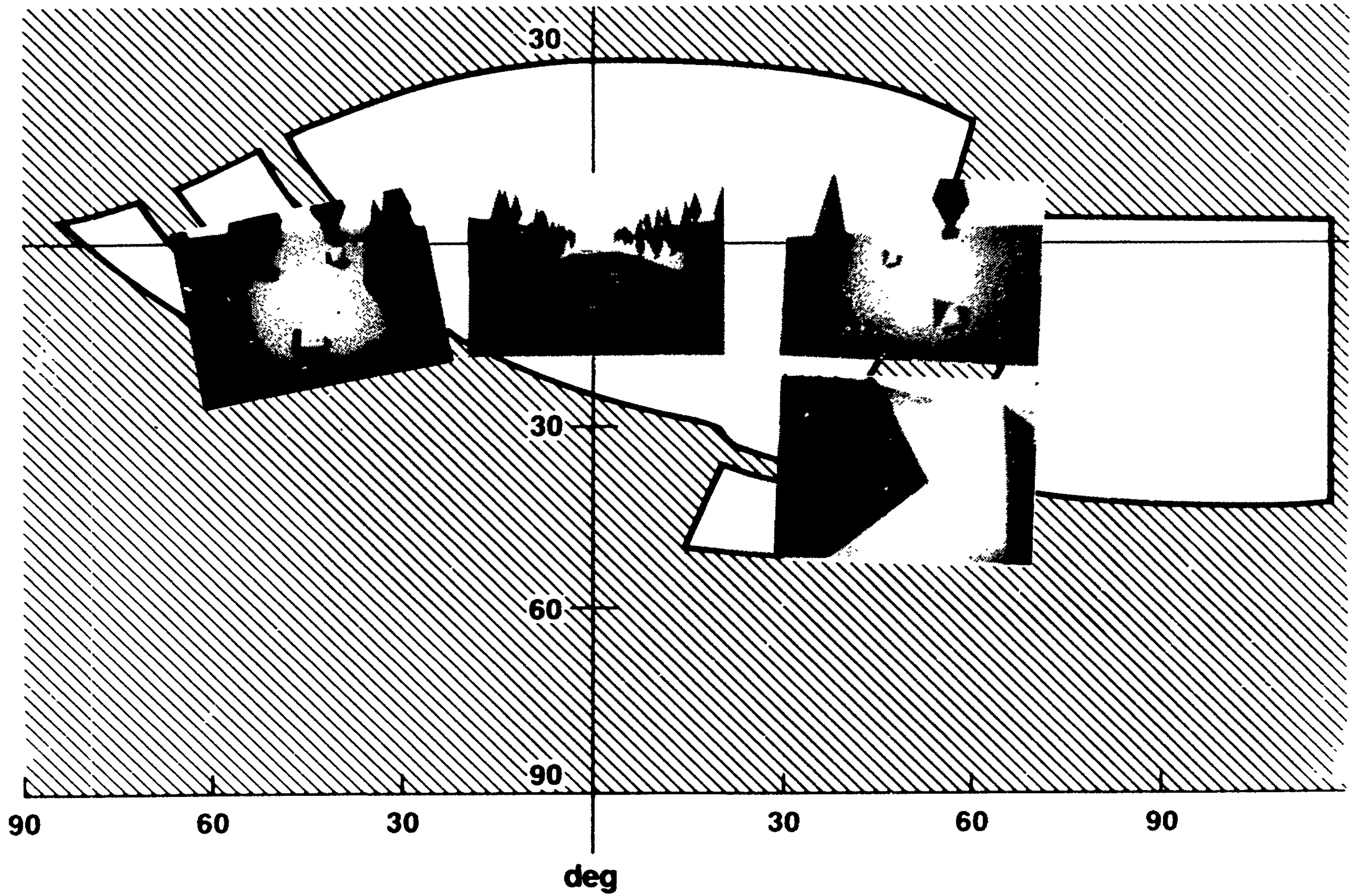


Figure 15.- Four-window computer-generated display of CGI terrain scene.

Effect of Learning on Pilot Ratings

Ratings as an assessment technique vary considerably in reliability as a function of the characteristics of the raters (training and experience), and of the rating situations (objects rated, instructions). By issuing precise instructions and randomizing the various configurations over the course of the experiment, it was felt that the effects of learning due to time would be greatly diminished. It can be seen from figure 16 that the relative effects of learning for all of the tasks were insignificant. If learning had taken place, the averaged ratings would tend to decrease as the test progressed through each run. Therefore, the pilot ratings given at the beginning of the experiment can be analyzed with the ratings for the primary test configurations presented later.

Analysis of Variance

Before any attempt was made to elaborate on the theoretical or practical meaning of the yaw control rating data, an analysis of variance was conducted on the

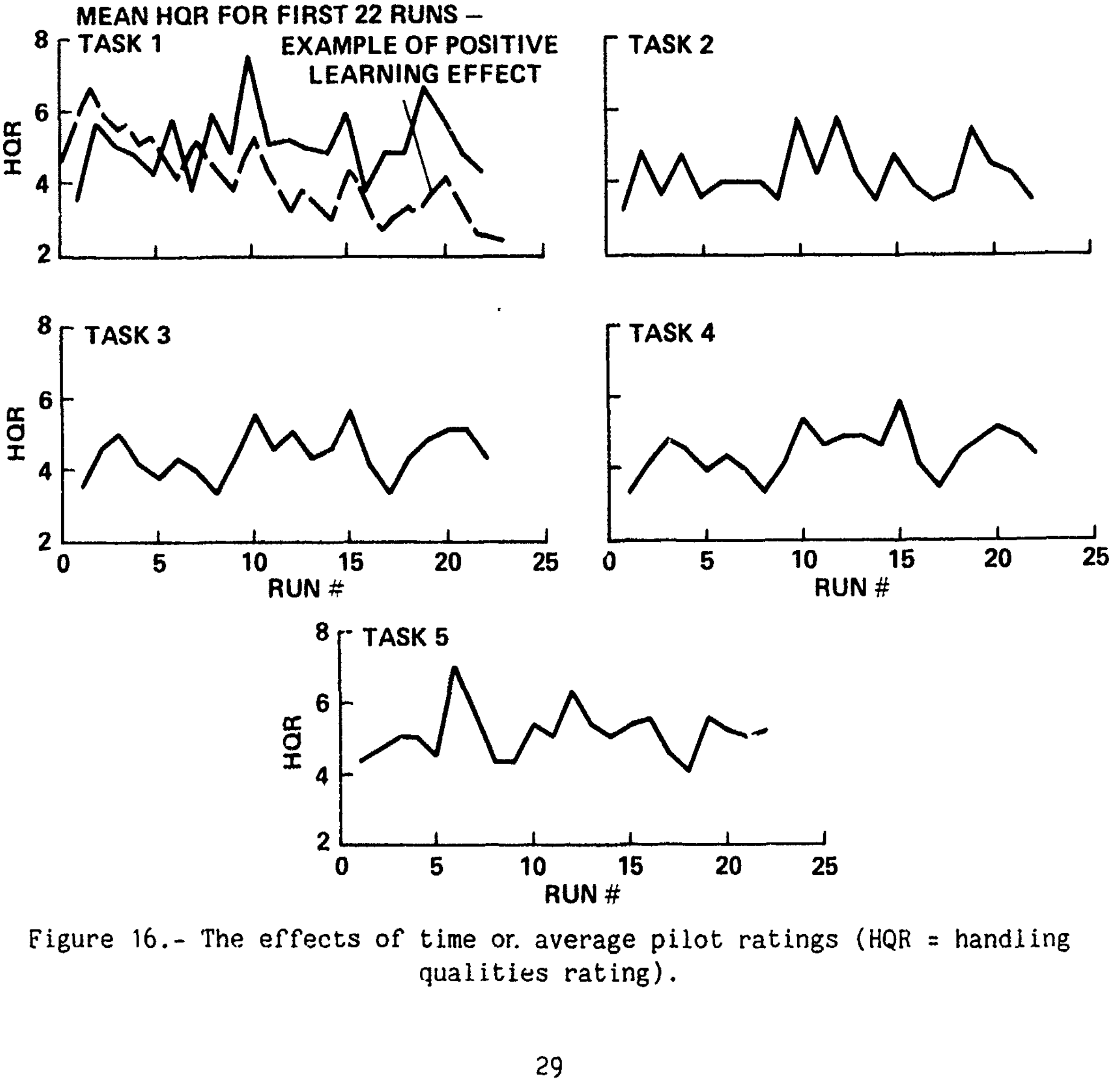


Figure 16.- The effects of time on average pilot ratings (HQR = handling qualities rating).

rating data for the primary test configurations. The goal of this analysis was to determine whether differences in ratings due to variations in configuration, turbulence, task, or their interactions were (or were not) greater than what could be attributed to chance (ref. 33). A summary of the analysis-of-variance results is presented in table 4.

TABLE 4.- SUMMARY OF ANALYSIS OF VARIANCE RESULTS

Source of variance	Degrees of freedom	Mean square, $\bar{X}^2$	F	Probability*
Between configurations	10	13.8	5.82	0.001
Between turbulence and no turbulence	1	132.5	7.11	.076
Between tasks	4	15.4	4.95	.01
Configurations × task	40	1.33	2.11	.001
Configurations × turbulence × task	40	1.19	1.72	.01

*Level of significance $\alpha \leq 0.05$.

Table 4 shows that the Cooper-Harper rating data for the primary test configurations exhibited four statistically reliable sources of rating variance:

a) Variance due to differences in configurations

b) Variance due to differences in task

c) Variance due to the interaction between configuration and task

d) Variance due to the interaction between configuration, task, and turbulence

The statistical significance of these sources of variance indicates that there are systematic (non-chance) differences between two or more of the rating means within each source category. Therefore, the test configurations, tasks, and their interactions affected the present handling quality ratings. Contrary to what was expected, the presence/absence of turbulence did not affect the mean handling qualities ratings (HQRs) when the ratings were averaged across all configurations and tasks. These findings were used as a basis for discriminating between real differences in the handling qualities ratings and those differences due to sampling error. As a result, a practical meaning of the results could be derived with a reasonable degree of confidence. It must be noted that this analysis only tells one that at least one of the means is different from the others. Additional analyses, or an inspection of the magnitude of the means themselves is required to tell which

means are different. Also, determining whether or not a statistically significant difference between means has any practical importance is left to the judgment of the researcher.

Correlation of Individual Pilot Ratings with the Average Ratings

The reliability of the assessment of the flying qualities of configurations, when the pilot is asked to rate and comment on the configuration while performing specific tasks, is improved with an increase in the number of evaluation pilots. This could not wholly be accomplished due to the fixed number of simulation hours and required number of configurations to be evaluated. But high reliability can be maintained if each of the evaluation pilots consistently correlates well with the average (ref. 10). Each pilot's rating must be independent of time and have a high index of correlation with the average ratings. This index of correlation is a measure of how well his sensitivity to configuration changes (as reflected in his ratings) correlates with the sensitivity of the average ratings to the same configuration changes. The results of the correlations between the individual ratings of the primary test configurations and the average ratings across all four evaluation pilots are given in appendix F. This analysis also provided a measure of the average deviation to be expected in the observations and an approximate criterion for rejection of a particular rating or evaluation pilot.

An index of correlation of unity represents a perfect 1 to 1 correlation between the particular pilot rating and the average, while an index of correlation of zero indicates zero correlation of the pilot rating with the average. The index of correlation for the pilots for each task is shown in table 5. The index of correlation for all four pilots was moderately high except for two cases (Deceleration pilot 3, Fire-control pilot 2) showing that their sensitivity to configuration changes was basically the same as the average. Since the correlation was very low in the Fire-control case for pilot 2, and it appeared that his sensitivity to configuration changes was negligible (the difference in his ratings due to scatter), pilot 2's ratings were rejected for the fire-control task. Also, the ratings for

TABLE 5.- SUMMARY OF PILOT CORRELATION ANALYSIS

	Task				
Pilot	NOE	Deceleration	Low turn	High turn	Fire control
1	0.77	0.78	0.70	0.76	0.72
2	.78	.81	.79	.77	.18
3	.71	.40	.68	.77	.72
4	.84	.79	.79	.72	.71

pilot 3 during the deceleration maneuver were rejected, since a value of 0.40 is statistically not any different than zero. For $N = 21$, a correlation of 0.43 is required for a significance of ≤ 0.05.

Damping and Yaw Gust Sensitivity

For NOE flight, deceleration and hover turns, higher levels of yaw weathercock stability (N_v) required higher levels of damping (N_r) to achieve level 1 handling qualities (fig. 17). With the addition of wind and turbulence, these same values of N_v required an even higher level of damping to achieve level 1 handling qualities.

It was also illustrated that the task does affect the level of yaw damping required for each of the N_v's tested. It appears that the more the task demands control activity in the yaw axis, the more yaw damping is required. In the deceleration task, very low damping levels can be tolerated for all levels of N_v. In performing this task the pilot is only controlling the yaw axis to maintain the nose along the direction of flight. In the NOE task, yaw control becomes more important in that the pilot is using the yaw axis controller in coordination with the roll controller in negotiating the turns throughout the course. Correspondingly more damping is required as N_v increases. When the pilot performs the hover task, he is then controlling mainly the yaw axis. In this case the required levels of damping are the highest for increasing values of N_v. This same trend also occurred for a different task when turbulence/wind was added. It can be seen from figure 17 that the minimum levels of damping increased considerably and the increase in slope corresponds to the type of task performed. The only configurations that maintained level 1 handling qualities for all of these tasks with turbulence were configurations:

37 $\quad N_v = 0.001,\ N_r = -4$

29 $\quad N_v = 0.0025,\ N_r = -4$

These values correspond to an ABC or XV-15 type of aircraft with an added yaw damper.

In this experiment, control sensitivity (N_{δ_p}) was held as a dependent variable and only changed with yaw damping. It must be recognized though that all three variables (N_v, N_r, N_{δ_p}) should be considered when establishing a criteria. Using data from references 10 and 11, and data obtained in this experiment, the following 3-dimensional plots were obtained (figs. 18 and 19) for NOE and hover flight. It can be readily seen that a criteria for yaw handling qualities should encompass all of these variables for a given task. A minimum level of damping can be specified, but its value is also dependent on N_v and N_{δ_p}.

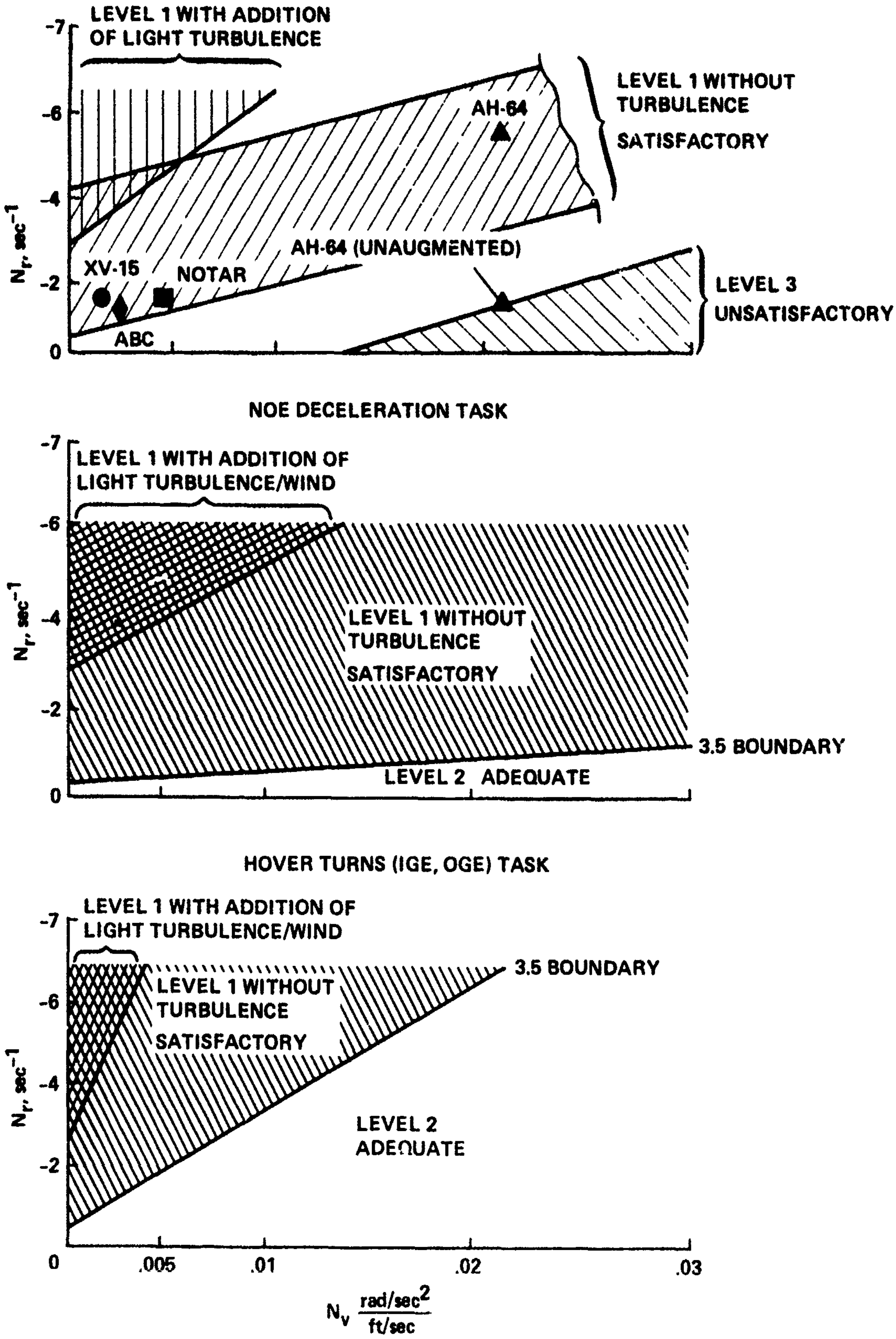


Figure 17.- N_r versus N_v.

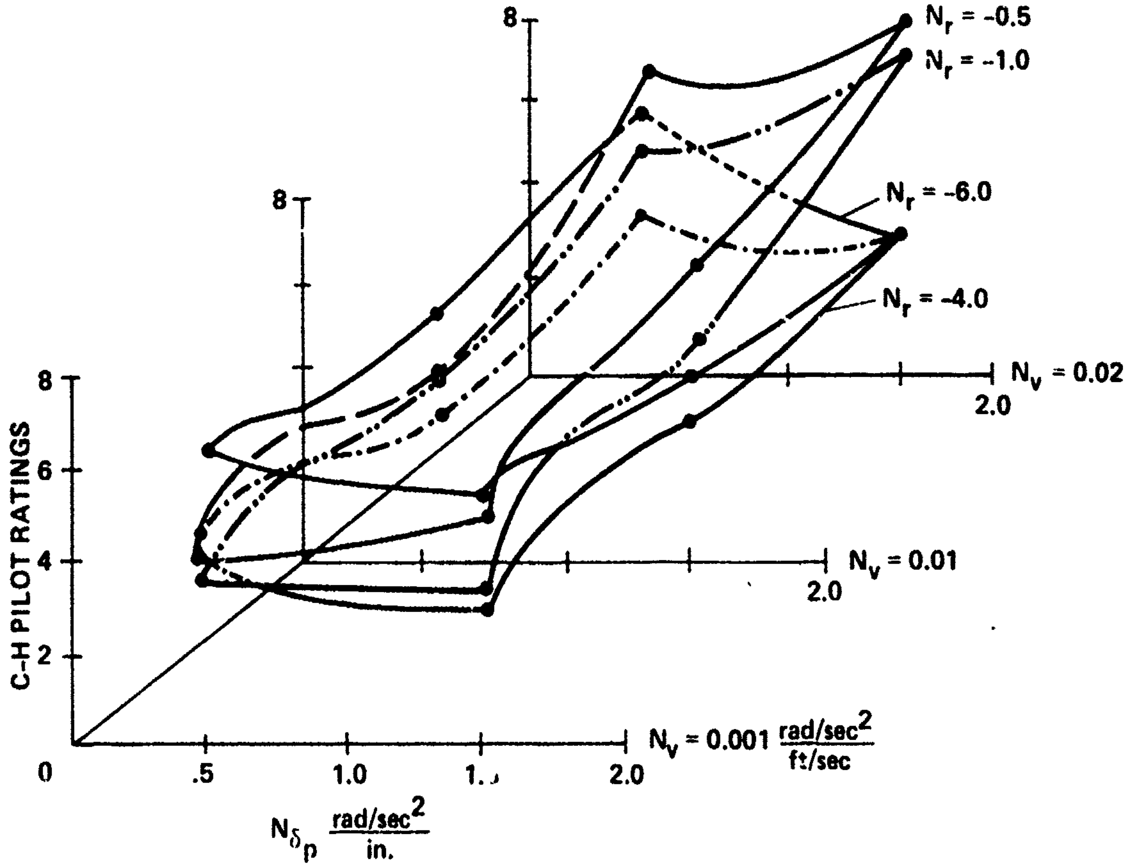


Figure 18.- Composite of yaw damping, sensitivity, and weathercock stability data (NOE task) without turbulence.

Yaw Control Response

For the fire control task, no statistically obvious trends in pilot rating with N_r and N_v were apparent. Reference 13 states that, "The pilot's awareness of the controllability and maneuverability of the vehicle is influenced primarily by its short-term-attitude response to control inputs." A means of identifying this short-term response in the yaw axis is by calculating the heading response in 1 sec to a unit pedal input for each configuration. The values of yaw damping and heading response which yielded level-1 handling qualities for the air-to-air fire-control task are indicated in figure 20. Level-1 handling qualities were obtained only for responses between 10-17° after 1 sec for 1-in. of pedal deflection and damping levels between -2.5 and -4 sec^{-1}. Military specification F-83300 states that the minimum and maximum heading responses for level-1 handling qualities are 6-23° after 1 sec for 1 in. of pedal deflection, but no specific relationship to yaw damping values or specific tasks are specified. In analyzing the air-to-air missile fire control task and pilot comments, it was observed that the pilot desired to quickly move the aircraft to align the sight of the target with a minimum of overshoot or undershoot. Pilot comments taken from the configurations lying in the area outside the level-1 handling qualities region of figure 20 may be summarized as:

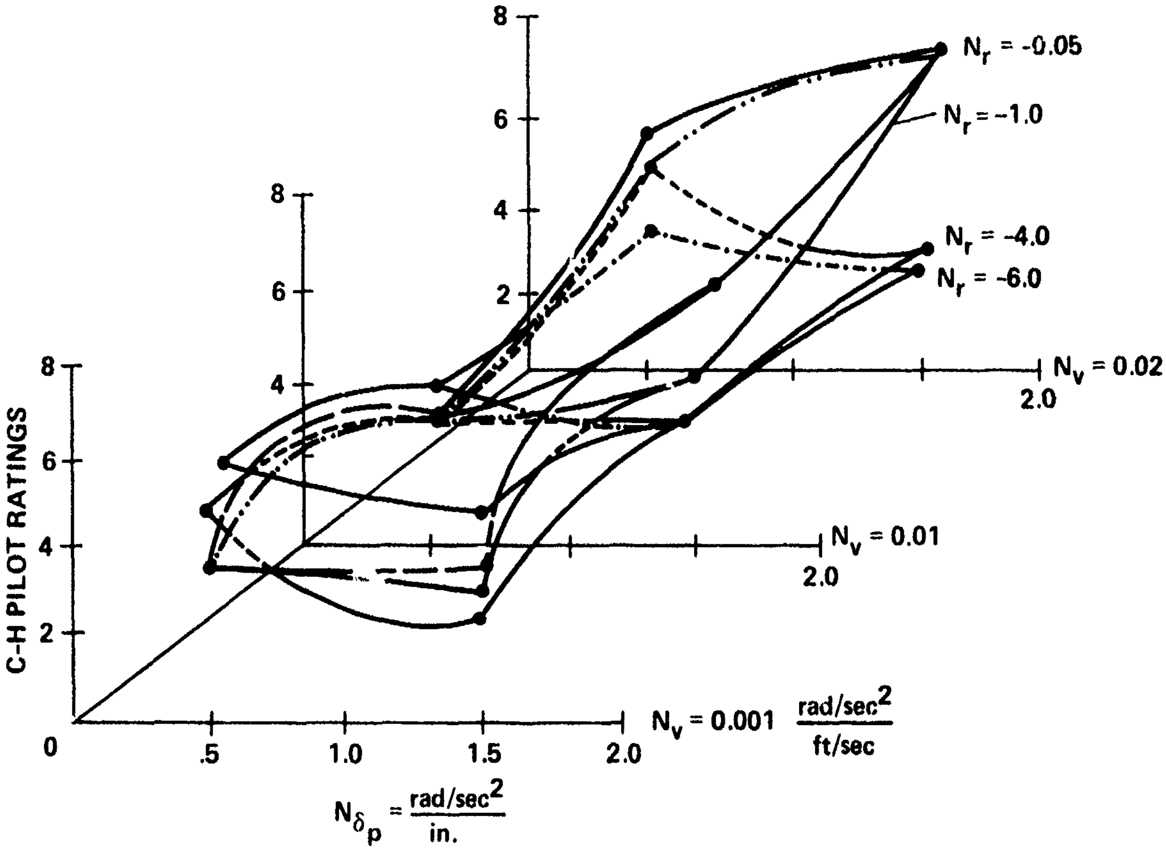


Figure 19.- Composite of yaw damping, sensitivity, and weathercock stability data (hover task) without turbulence.

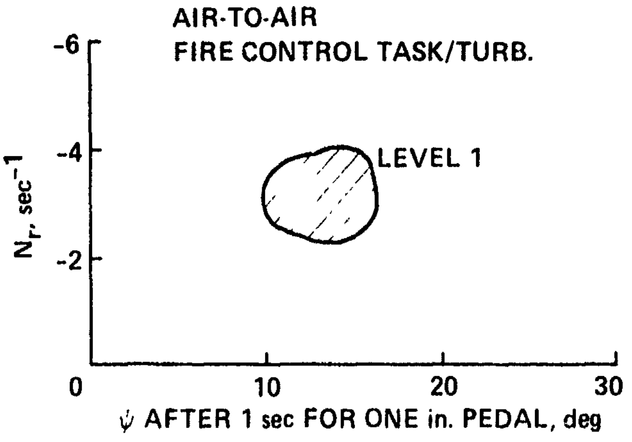


Figure 20.- Yaw damping versus control response for the air-to-air fire-control task (with turbulence).

$\psi < 10°$ after 1 sec for 1 in. pedal--The pedals are too insensitive for acquisition and tracking.

$\psi > 17°$ after 1 sec for 1 in. pedal--The pedals are too sensitive for acquisition and tracking.

$|N_r| > 4$--Aircraft displayed control ratcheting when tracking.

$|N_r| < 2.5$--Aircraft keeps overshooting and undershooting the target. It is hard to get the aircraft settled down on a consistent rate.

Examples of this are illustrated in figure 21. The configurations that received good ratings had a very good response and were optimally damped, which accounted for minimum time and tracking error. The configurations that received poor ratings either had poor response or were not optimally damped, thus it was extremely hard to get the sight aligned with the target within the allotted time constraints.

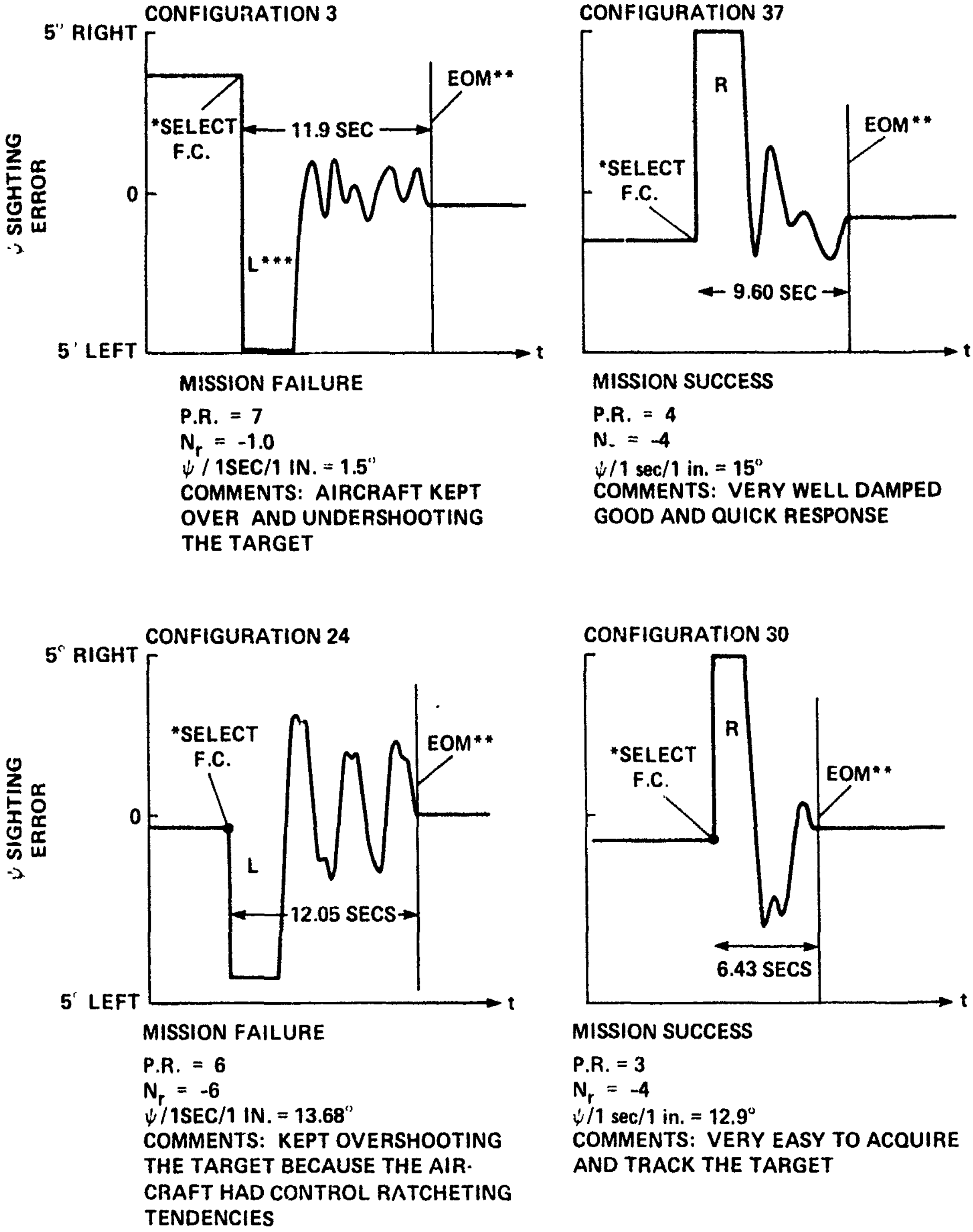
These results are for an air-to-air task with the target aircraft traveling at a constant velocity of 60 knots and at a constant range of 1,000 ft. Variations in the target trajectory may very well affect the location of the level-1 region of the yaw damping-response plane.

Level 1 control response data was also obtained for the NOE, deceleration, and hover task. These results are listed in table 6. It can be seen that for these tasks the MIL-F-83300 specification is a satisfactory criterion.

Response to Turbulence

An important result of the analysis conducted in reference 11 was that the minimum damping levels are apparently determined on the basis of the aircraft's response to turbulence, from either an open-loop or a closed-loop viewpoint. Minimum damping levels for a given task and boundary are lines along which the aircraft's heading response to turbulence is constant for all values of N_v. Therefore, as N_v is increased, the pilot requires increasing values of N_r to maintain the aircraft response to turbulence at the desired level. The values of σ_T selected for the level 1 boundary from the experiment conducted in reference 11 was 8° and 7°. This was for the visual and instrument approach task, respectively.

For the yaw control experiment, heading response data was obtained by generating σ_T over a period of 6 sec with light turbulence at a hover (appendix H). Heading response (σ_T) versus yaw damping for each of the N_v's was then plotted. These results are given in figure 22. It can be seen that for all values of N_v, σ_T decreases as damping increases. A linear correlation analysis was conducted between σ_T and N_r. The correlation coefficient was 0.79, which shows a moderately high correlation. It can also be observed that the higher the value of N_v, the more the yaw damping requirement is increased. The respective damping levels for values of N_v to achieve level 1 were:



* SELECT F.C. – STRIP CHART DATA STARTS WHEN PILOTS INITIATES MISSILE FIRE-CONTROL SIGHT ON HUD USING CYCLIC STICK SWITCH

** EOM - END OF MISSION (PILOT EITHER SHOOTS DOWN TARGET OR RUNS OUT OF TIME)

*** L,R – TARGET WAS INITIATED FROM EITHER THE LEFT OR RIGHT DIRECTION

Figure 21.- Examples of yaw axis control activity for the fire-control task.

TABLE 6.- LEVEL 1 CONTROL RESPONSE DATA FOR TASKS*

	NOE	Deceleration	IGE turn	OGE turn	MIL-F-83300
Minimum	6°	6°	7°	7°	6°
Maximum	12°	12.5°	13.5°	13.5°	23°

*ψ after 1 sec for 1 in. pedal (low turbulence/wind).

For N_v = 0.01, 0.02 -- N_r = -4.5

N_v = 0.005 -- N_r = -3.5

N_v = 0.001, 0.0025 -- N_r = -1.8

These values are in general agreement with previous results, but this criteria was only examined for the hover case and more research must be directed to investigate possible values for other tasks.

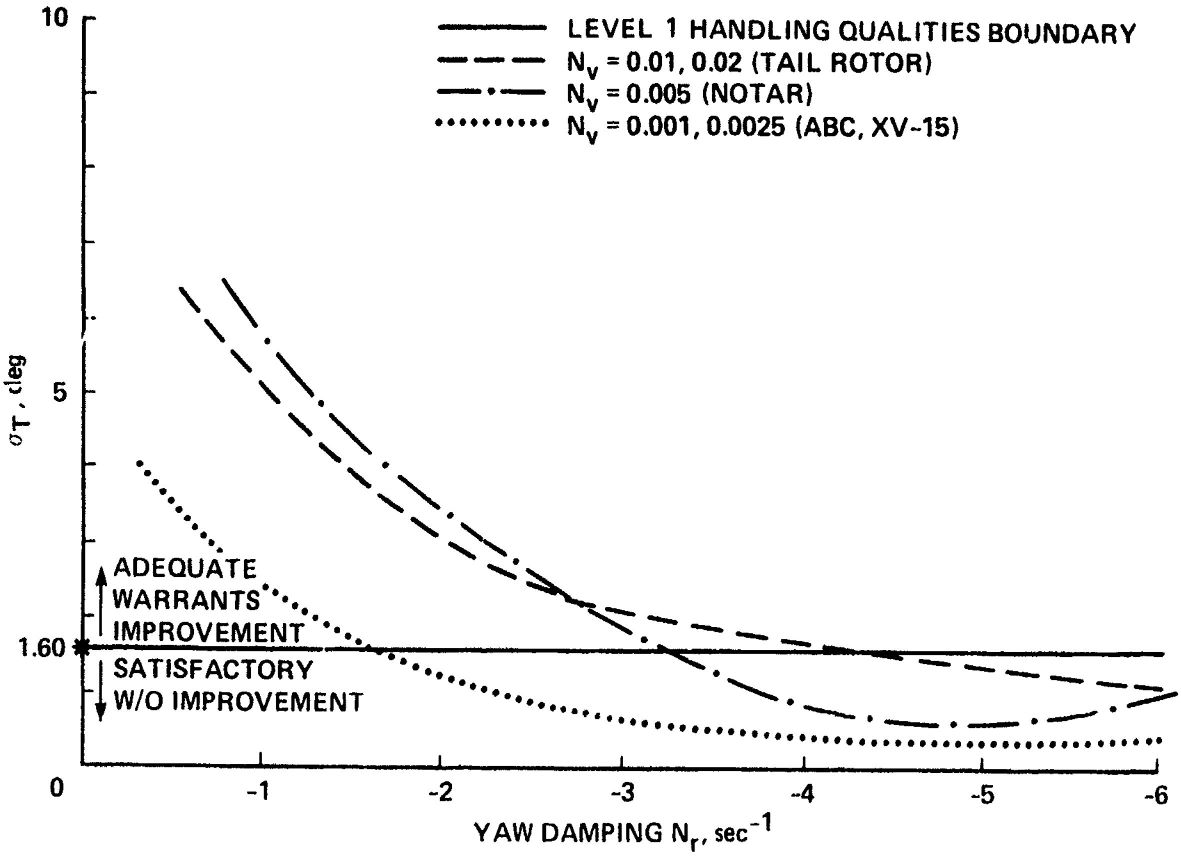


Figure 22.- Heading response due to turbulence with no pilot inputs (6 sec).

The maximum σ_T resulting for level 1 handling qualities was 1.6°. This differs considerably from a σ_T of 7° or 8° as obtained in reference 11. The possible difference may have come from the time period used to generate σ_T, the distinctive tasks, and the level of turbulence. These results show that it is possible to determine good handling qualities from open loop turbulence response. In order to become a viable criterion, however, the specific task, the time to generate σ_T, and the turbulence level must be thoughtfully considered.

Loss of Tail Rotor Control Effectiveness

This phenomena has been experienced operationally by many OH-58 series aircrews in the field (refs. 34 and 35). In investigating the loss of tail rotor effectiveness, a total of 47 data runs were obtained. The moderate and strong wind conditions were evaluated by one engineer/pilot and the remaining configurations were flown by four test pilots. The resulting Cooper-Harper ratings are presented in table 7.

TABLE 7.- COOPER-HARPER RATINGS FOR TAIL-ROTOR CONFIGURATIONS

		N_r, sec^{-1}				
		-.5	-1.0	-4.0	-6.0	WIND
N_v, rad/sec^2/ft/sec	0.02		5.75(4[1])	5.0	4.75	LIGHT
		10	10	5	4	MODERATE
		10	10	10	8	STRONG
	0.01	6.75	5.4	4.25	4.33	LIGHT
		10	10	5	3.5	MODERATE
		10	10	4	6	STRONG

1 YAW AUGMENTATION ADDED

LOSS OF TAIL-ROTOR CONTROL ENCOUNTERED

By modeling the first-order effects of N_r, N_v, and N_{δ_P} for different wind conditions and azimuths, it was possible to induce a right-spin which is characteristic of that encountered during loss of tail rotor control effectiveness in OH-58 series aircraft (refs. 34 and 35). These results do not imply that these are the only variables or circumstances to cause the phenomena; but, by investigating these factors, more groundwork was laid for further research.

For yaw damping levels of $|N_r| \leq 1.0$ with moderate or strong wind conditions, control of the aircraft was lost or the aircraft was flown into the surrounding terrain while the pilot was attempting to initiate a recovery. All of the loss of control incidents occurred during the 90° right turn, where a right spin was encountered. At no time did loss of control occur in the left turn; however, pedal margin limits were reached for certain configurations. The pilots flew the various configurations NOE through the left turn, having to turn the tail of the aircraft into the relative wind. Conversely the right turn required the tail to yaw with the direction of the wind. Pilot comments indicated that the very sharp right turn which took coordinated roll and yaw control inputs required a higher than normal yaw input (and subsequently a higher induced rate). This rate, combined with the added yaw rate due to the environmental right tail-wind moment for low damped configurations, forced the yaw rate and accompanying acceleration to become even more aggravated. The tail rotor would then lose partial effectiveness due to receiving a relative wind coming from ψ angles of 30° to 90° (fig. 7). Depending on the severity of the wind, yaw rate induced by the pilot, the yaw damping of the aircraft, and the effective change in yaw control power (ψ between 30° and 90° for increased relative velocities), the spin was induced. Figure 23 shows some of the aircraft dynamic states and control positions during a typical loss of control case. Additional pilot comments indicated that if the loss of control had occurred at a higher altitude (>200 ft), recovery might have been possible. At NOE altitudes, adding additional collective during the spin tended to aggravate the condition. When the pilots attempted to decrease the effect of main rotor torque by decreasing the collective, the result was usually ground or tree contact during the spin.

While performing the left turn, control wasn't lost even though control power margins may have been reached. In correlating this to figure 7, a left turn would generate a relative wind on the tail rotor from ψ angles of 270° to 330°. In this region, damping is adequate but increased thrust is required. Pilot comments implied that since the left turn wasn't as severe as the right, neither was the required left yaw rate. This left yaw rate was also diminished by the relative wind coming from the right. This caused the pilot to increase the left pedal in order to line up the nose with the line of flight. They would continue adding pedal until the margin was reached. Since no large yaw rates were encountered, the pilot would be in a steady state condition with full left pedal. The pilots commented that this was not desirable, but they could compensate for this condition by adding left cyclic and flying with the nose of the aircraft out of trim to the right. This is also illustrated in figure 23.

By decreasing the value of the aircraft directional gust sensitivity parameter (N_v) from 0.02 to 0.01 in strong winds, it was observed that pilot ratings improved for yaw damping values of -4.0 and -6.0; for damping values of -0.5 and -1.0 in moderate and strong winds, aircraft control was lost for both values of gust sensitivity. For light winds, no degradation in pilot rating with increasing gust sensitivity was evident ($N_v \cdot v_g$ is insignificant).

Due to the excellent nature of the engine governing system, the rotor rpm changed less than ±1.0%. Even though the rpm effects were coupled to the aircraft

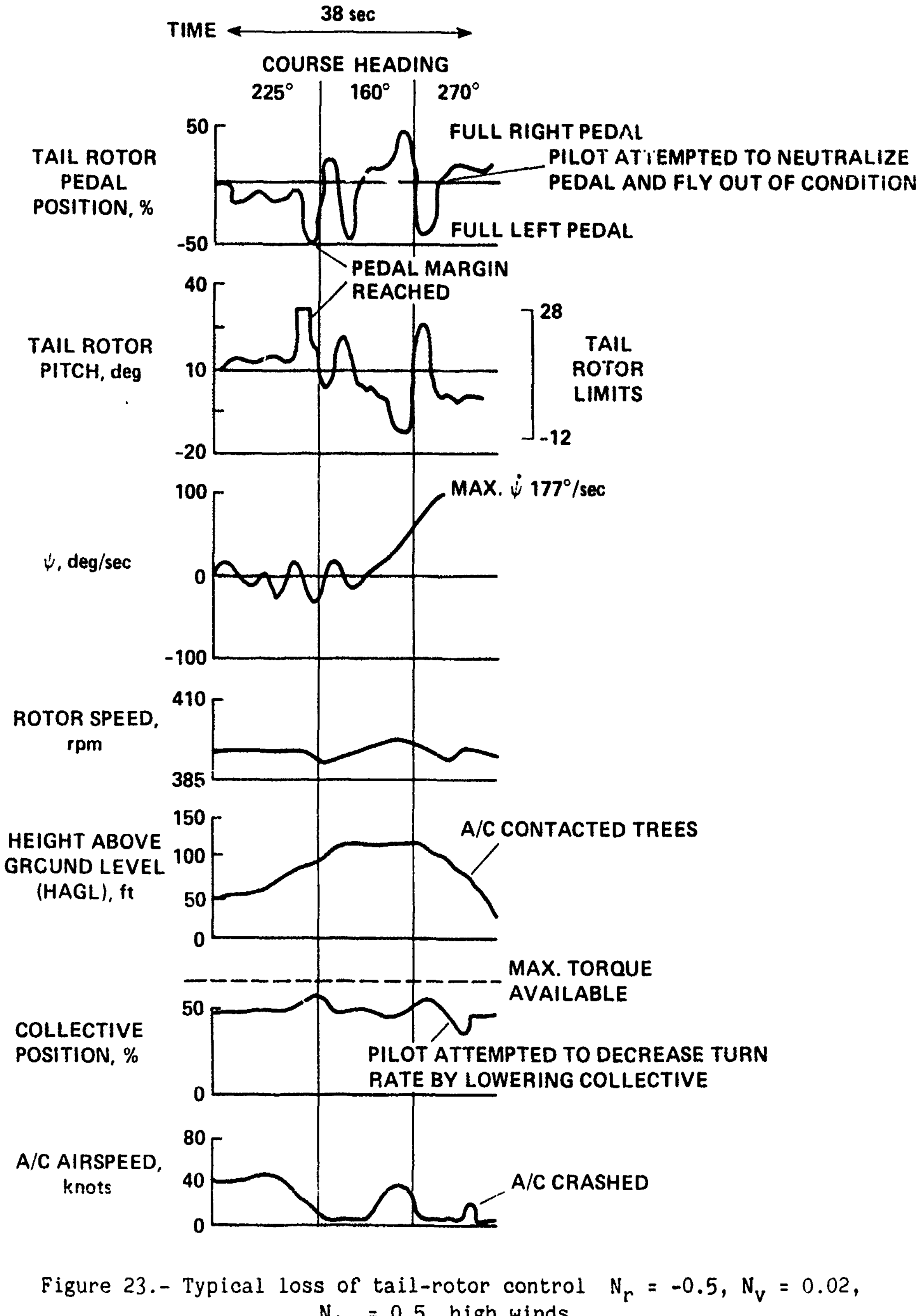


Figure 23.- Typical loss of tail-rotor control N_r = -0.5, N_v = 0.02, N_{δ_p} = 0.5, high winds.

yawing moment, a 1% drop in rpm required only a 0.3 in. change in required left pedal (δ_p) for trim conditions. Pilot comments further supported that rpm control was not a major factor inducing or aggravating the loss of yaw control effectiveness in this experiment. This result does not imply that poor rpm control is not a factor in tail rotor loss of control; but, that with a very good governor, rpm control is eliminated as a factor.

By adding a yaw SCAS or rate-command heading-hold augmentation to a configuration with low yaw damping (N_r = -1.0), the averaged pilot ratings improved. The pilots commented that the nose of the aircraft had less of a tendency to oscillate and it was very easy to modulate the yaw rates.

Bandwidth Analysis

Bandwidth is a qualitative measure of the input-to-output response of a dynamic system. Since it is a measure of the system input-to-output response, multi-parameter changes within the system should be captured. This phenomenon makes bandwidth an attractive criterion. Bandwidth analysis is conducted in the frequency domain and results in a fundamental measure of the ability of the system output to follow the system input. A higher system bandwidth reflects a faster and more predictable aircraft response to control inputs. The input and output quantities selected to define the system bandwidth are those most appropriate to the task being evaluated; for example, heading regulation involves rudder pedals as the input and yaw angle or rate as the output.

The bandwidth hypothesis (ref. 36) originated from the idea that the pilot's evaluation of aircraft handling qualities is dominated by the response characteristics of the aircraft when it is operated in a closed-loop tracking task. That is, the pilot's capability to make rapid and precise control inputs to minimize errors, and thereby improve closed-loop tracking performance, dominates his evaluation. The classical definition of closed-loop bandwidth (ref. 36) is the frequency at which the Bode amplitude is 3 decibels (dB) less than the steady-state amplitude of the system. For a closed-loop system characterized by a first-order response, the bandwidth as defined above is also the crossover frequency of the constituent rate-ordering (K/S) open loop as shown on the left side of figure 24. In this figure, the crossover frequency is labeled ω_c, and the bandwidth T; the latter to signify that bandwidth here is a direct measure of the closed-loop time response to a step command as shown on the right side of figure 24. In this case, crossover frequency, bandwidth, and the inverse of the response time are identical.

In general, such exact unity does not carry over to higher-order systems. Nevertheless in many cases, including those of flying qualities interest, the bandwidth as defined above is close, but not exactly equal, to the crossover frequency. In the field of aircraft flying qualities, "bandwidth" (defined by the highest open-loop crossover frequency attainable with good closed-loop dynamics) is typically used to measure the speed of response a pilot can expect when tracking

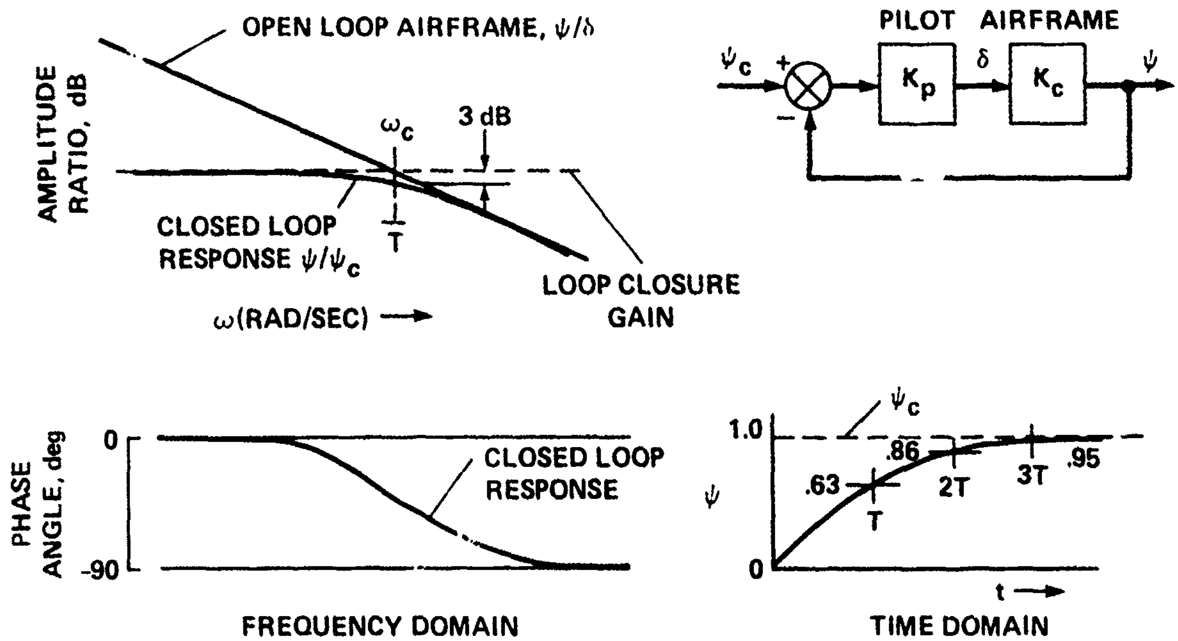


Figure 24.- First-order bandwidth/response relations.

with rapid control inputs. Bandwidth indicates how tightly he can close the loop without threatening the stability of the pilot/vehicle system; it is a measure of tracking precision and disturbance rejection. For precise tracking tasks, maximizing open-loop stability and damping allows the pilot to track high-frequency inputs and reject disturbances without unacceptable oscillations due to low damping in the closed-loop system.

Bandwidth hypothesis- Since the open-loop crossover frequency is equal to (and, for higher-order systems, approximately equal to) the classical closed-loop bandwidth, the definition of bandwidth and crossover frequency are equivalent. That is, the system bandwidth is defined as the crossover frequency for a simple, pure gain pilot with a 45° phase margin or a 6 dB gain margin, whichever frequency is lower (fig. 25). The basis of this criterion comes from gathered data that express the relationship between closed-loop damping and open-loop phase margin for an ideal open-loop plant (ref. 36).

Physical significance of bandwidth. A pilot will attempt to equalize the open-loop response characteristics (Kp,Kc of fig. 24) to a K/S shape. Controlled elements requiring lag equalization are generally downgraded a minimal amount, whereas requirements for significant amounts of pilot-generated lead (T_L > 1 sec) are characteristically unsatisfactory (ref. 36). The considerations that were implicit in using bandwidth as handling qualities criterion are summarized as follows:

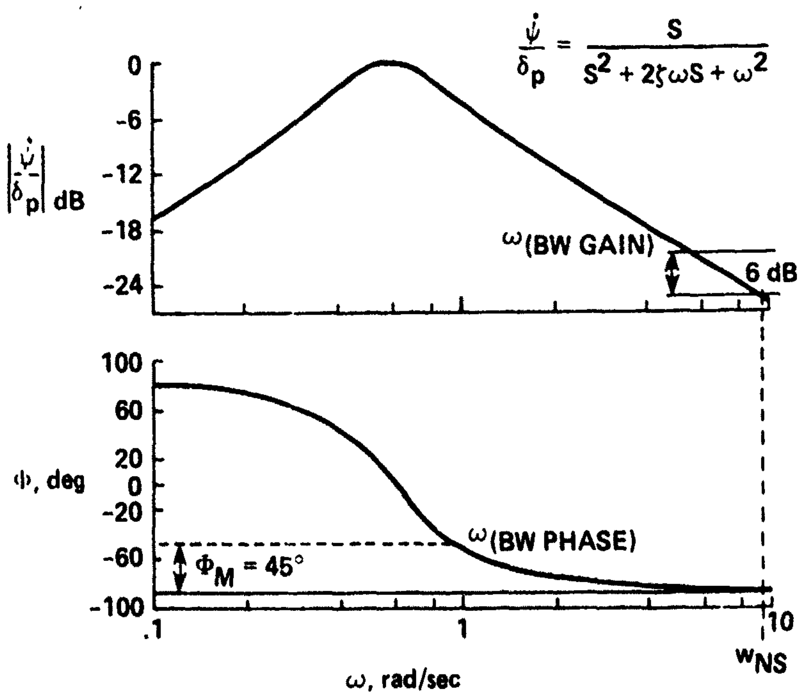


Figure 25.- Definition of closed-loop bandwidth, ω_{BW} (ω_{BW} = lesser of $\omega_{BW_{PHASE}}$ or $\omega_{BW_{GAIN}}$).

1. Bandwidth is a measure of risetime or speed of response $1/T_R \doteq -N_r$ (yaw damping) or $-Z_w$ (heave damping).

2. The closed-loop system bandwidth is approximately equal to the crossover frequency for a pure pilot gain (3 rad/sec yaw).

3. Low values of bandwidth are indicative of a need for pilot lead equalization and hence poor ratings.

4. Requiring a minimum value of bandwidth is equivalent to requiring rapid responses to control inputs without overshoots or any other undesirable characteristics of low damping (see Root Locus Analysis--Appendix I). If such characteristics are not available through the basic airframe, stability augmentation may be required. But still the control response characteristics are limited by certain inherent aerodynamic derivatives, which for the yaw axis are:

$$\frac{N_{\delta_p}}{s^2 - N_r s + N_v U_o \cos \psi_o}$$

even if the aircraft is perfectly decoupled.

Pilot modeling. A closed-loop bandwidth analysis using a simplified pilot model was investigated to see if pilot modeling could be used as a predictive tool

for yaw-control handling-qualities research. The assumed form of the pilot's transfer function was:

$$P(s) = K_{\dot{\psi}}\, e^{-\tau S}$$

where $K_{\dot{\psi}}$ is the pilot gain and τ is the reaction time delay (fig. 26). For $e^{-\tau S}$, the Padé approximation (expanded to the fourth term) was used:

$$\text{where} \quad e^{-\tau S} = \frac{1 + \frac{-\tau}{2} S + \frac{1}{2}\left(\frac{-\tau S}{2}\right)^2 + \frac{1}{6}\left(\frac{-\tau S}{2}\right)^3}{1 + \frac{-\tau S}{2} + \frac{1}{2}\left(\frac{\tau S}{2}\right)^2 + \frac{1}{6}\left(\frac{\tau S}{2}\right)^3}$$

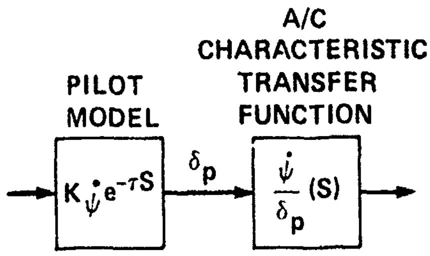


Figure 26.- Pilot model and aircraft transfer function.

with the initial value of τ set to 0.3 sec, which is representative of the human neuromuscular time delay. The computations consisted of adjusting the pilot's gain $K_{\dot{\psi}}$, as a function of N_r, N_{δ_p}, N_v to give a selected phase margin (30°) at the crossover frequency (frequency at which the open-loop amplitude ratio is unity). A value of 3 rad/sec was used as the constant crossover frequency, which assumes that the pilot adjusts his characteristics to maintain this constant value. The selected value of 3 rad/sec yields the optimum lead for the values of N_v and phase margin (ref. 11). In this analysis, the pilot was assumed to be performing a constant heading task while the aircraft was disturbed in heading caused by lateral turbulence, so that the pilot reacted to suppress the deviation of aircraft heading from the reference heading. Therefore, in closing the loop he performed a "compensatory" task (ref. 11).

Bandwidth results. To characterize the configurations evaluated by the pilot in the yaw-response simulation, an idealized heading-rate-to-pedal control-input transfer function $\dot{\psi}/\delta_p$, was assumed. From this transfer function, Bode plots were obtained for open-loop and pilot-in-the-loop analyses, using the matrix of the experimental variables that were evaluated (Appendix J). An idealized form of this transfer function may be assumed with good confidence because the mathematical helicopter model (ref. 25) used for these studies was a small-perturbation model utilizing stability derivatives as functions of velocity. The open-loop system block diagram, including the assumed form of the transfer function where $Y = \dot{\psi}/\delta_p$, is shown in figure 27. A linear analysis computer program (ref. 37) was used to obtain the open-loop Bode plots and to perform the closed-loop pilot model analysis

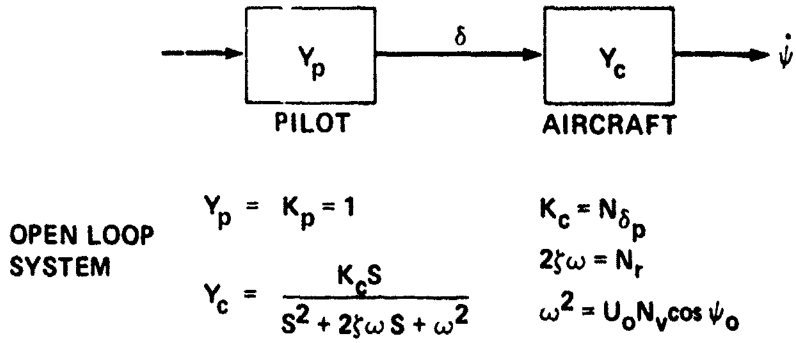


Figure 27.- Yaw response block diagram for open-loop analysis.

(Appendix J). Figures 28-31 show an evaluation of the open-loop heading rate bandwidths ω_{BW} for the experimental matrix of variables versus the averaged Cooper-Harper pilot ratings for the NOE task, the deceleration task, the low-hover turns

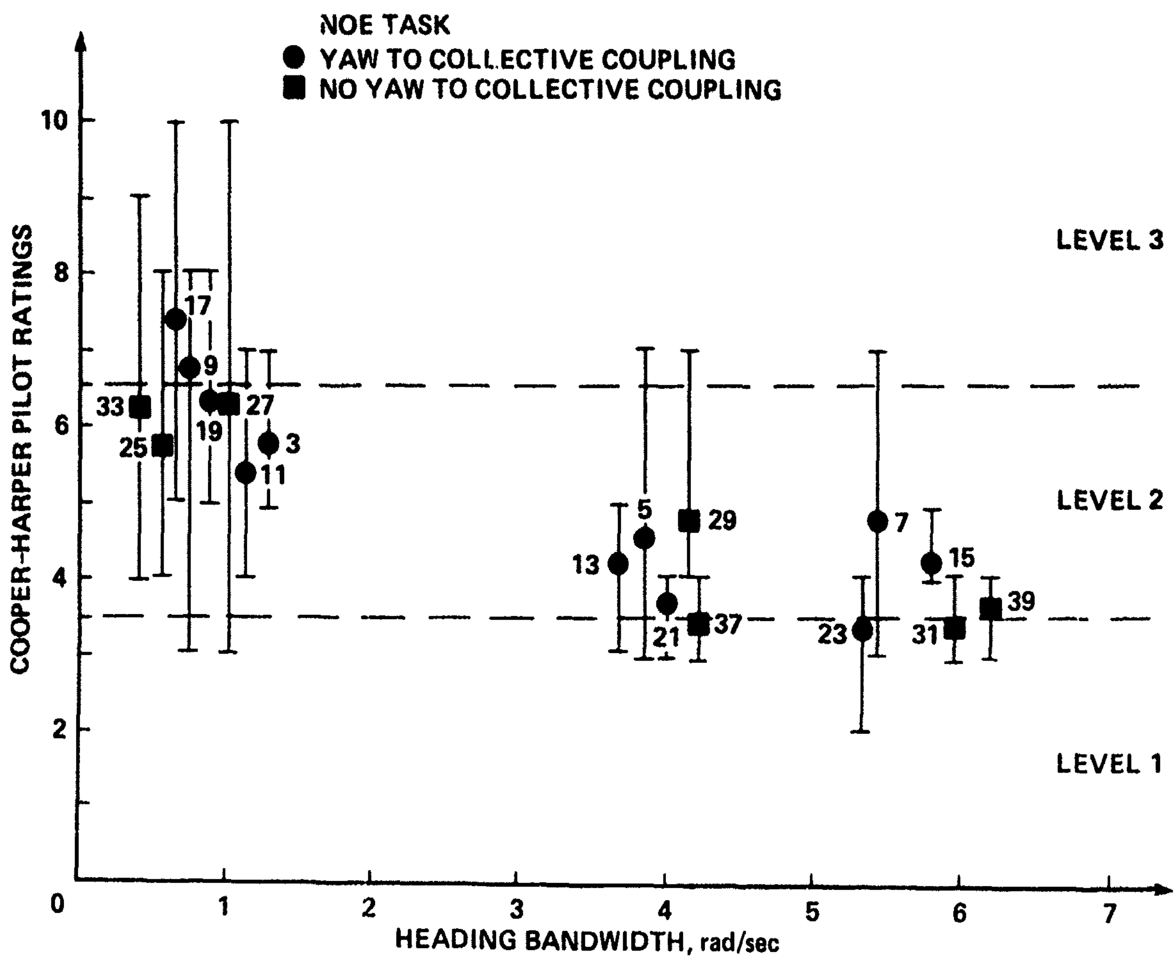


Figure 28.- NOE task - pilot ratings versus heading bandwidth.

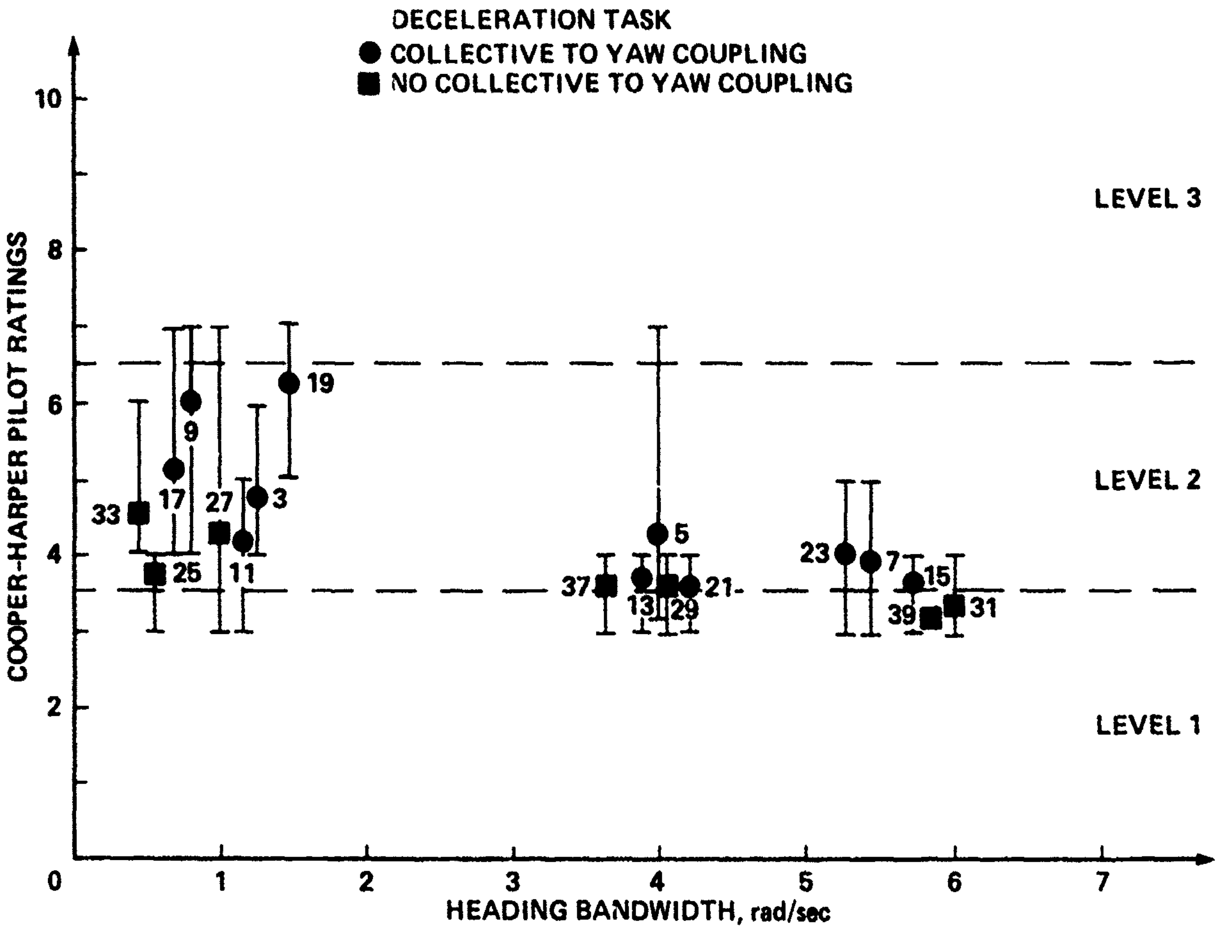


Figure 29.- Deceleration task - pilot ratings versus heading bendwidth.

task, and the air-to-air target-acquisition task. The high-hover turn was omitted here because of similarities between those data and the low-hover turn data.

For the NOE task and low-hover turns, bandwidths greater than 3.0 rad/sec resulted in substantially better handling qualities. At these higher values of bandwidths, however, the ratings range from 3 to 5 and do not consistently stay in the level 1 region. The bandwidth where the deceleration task gets considerably better ratings appears to be at values greater than 3 rad/sec. For the air-to-air engagement task, there was no readily correlated bandwidth for good handling qualities of the tested configurations. Since the bandwidth can be assumed to be a measure of the speed of response, the results of the air-to-air targeting task suggest strongly that there is a specific range of bandwidth values which will yield level 1 handling qualities, and that these values can only be obtained by optimizing N_{δ_p} and N_r for this task (see previous results for air-to-air task). This conclusion seems appropriate since the initial hypothesis assumes a defined compensatory tracking. The air-to-air tracking in this simulation is a variation of the above assumed tracking because the pilot is attempting to quickly match his yaw rate

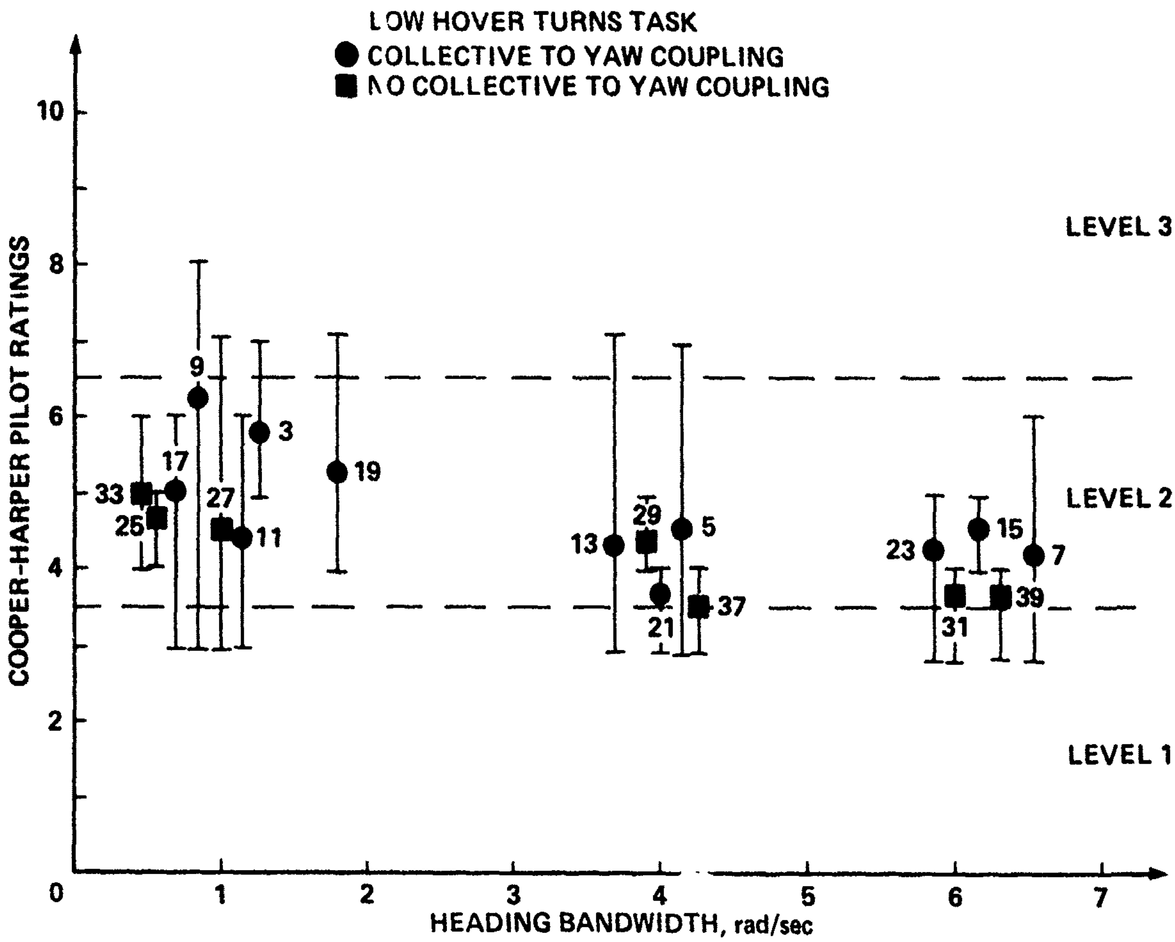


Figure 30.- Low hover turns task - pilot ratings versus heading bandwidth.

with the flightpath of the target ship while also simultaneously minimizing the missile aiming error.

The results for the NOE, deceleration, and hover tasks indicate that while a minimum bandwidth may be specified, this along with additional parameters (such as N_v, N_{δ_p}, or ψ response to pedal inputs) must be used in order to completely define a specification. Finally, an investigation was made into the use of a simple pilot model as a predictive tool for yaw-control handling-qualities research. The pilot gains resulting from the closed-loop pilot analysis (Appendix J) were correlated with the Cooper-Harper pilot ratings for the NOE task (fig. 32). The correlation indicates that a pilot gain of 4 will yield better handling qualities than a configuration that requires a gain of 6. Even though a configuration may require a pilot gain of only 4, it may still be only a marginally satisfactory configuration. In looking at figure 32 it is evident that even at the lower pilot gain values, configurations with high gust sensitivity still were marginally satisfactory configurations. In order to fully categorize an aircraft using this data, one must have the derived pilot gain along with the aircraft gust sensitivity value. To look at the validity of this approach, a configuration with known marginal handling qualities

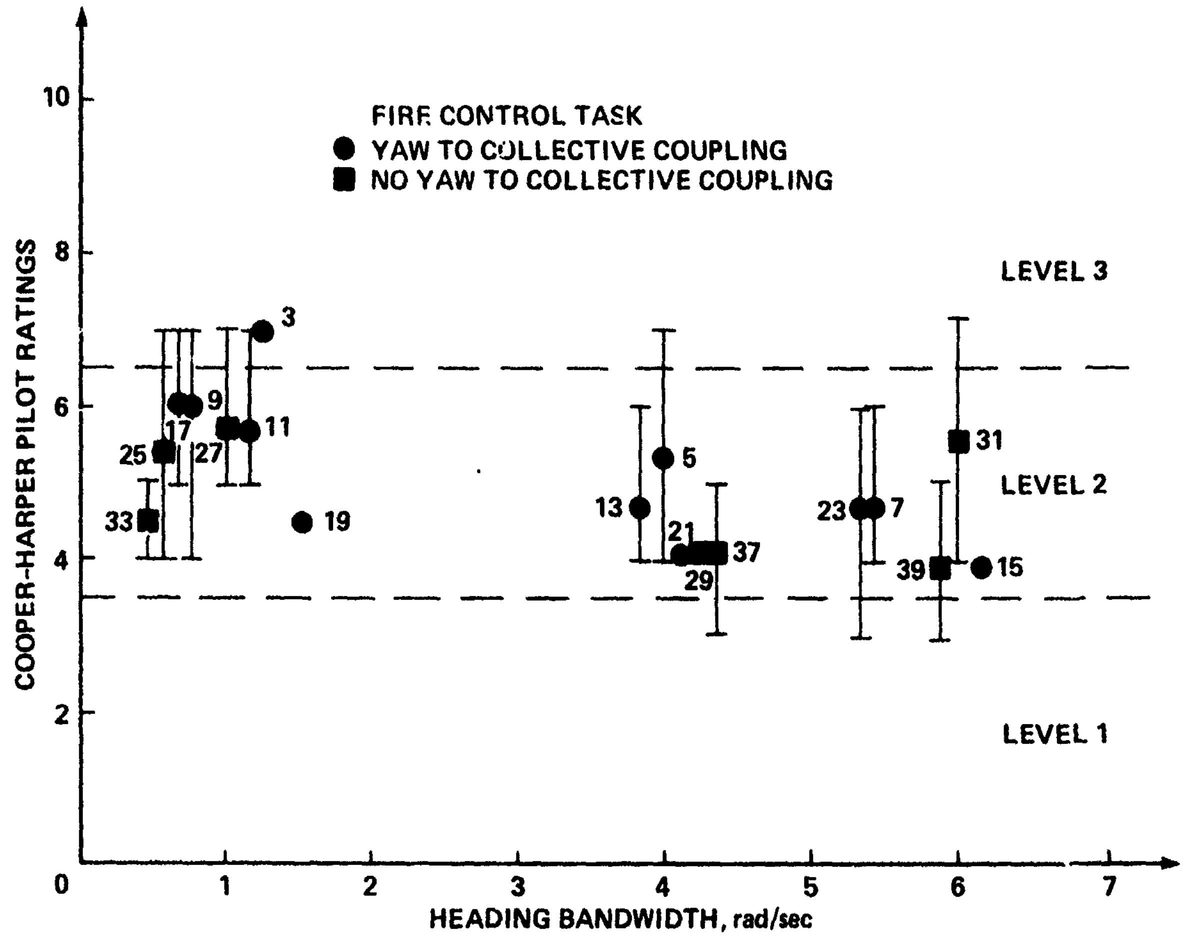


Figure 31.- Fire control task - pilot ratings versus heading bandwidth.

was analyzed (configuration 35). Using the closed-loop pilot techniques, this configuration yielded a pilot gain of 5.5. Comparing this value with the results presented in figure 32 shows this configuration to predict handling qualities in the level 2 region (a Cooper-Harper pilot rating of 6.5). This technique can provide a preliminary predictive capability, but other criteria (such as specifying $N_v \leq 0.01$) must also be used for a more complete specification.

Performance analysis- This method for assessing handling qualities involves the use of various objective measures of system performance. The assumption underlying this technique is that poor vehicle-handling qualities result in the degradation of certain aspects of system performance which are objectively measurable. Degradation of these measures is, in turn, assumed to be negatively correlated with mission achievement.

The performance approach has the advantage of measurement objectivity. It yields an objective record (for example, tracking error, airspeed error, and time to complete a task) as a function of variation in vehicle-control parameters. These measures can be reliable when treated with sophisticated techniques as stated in

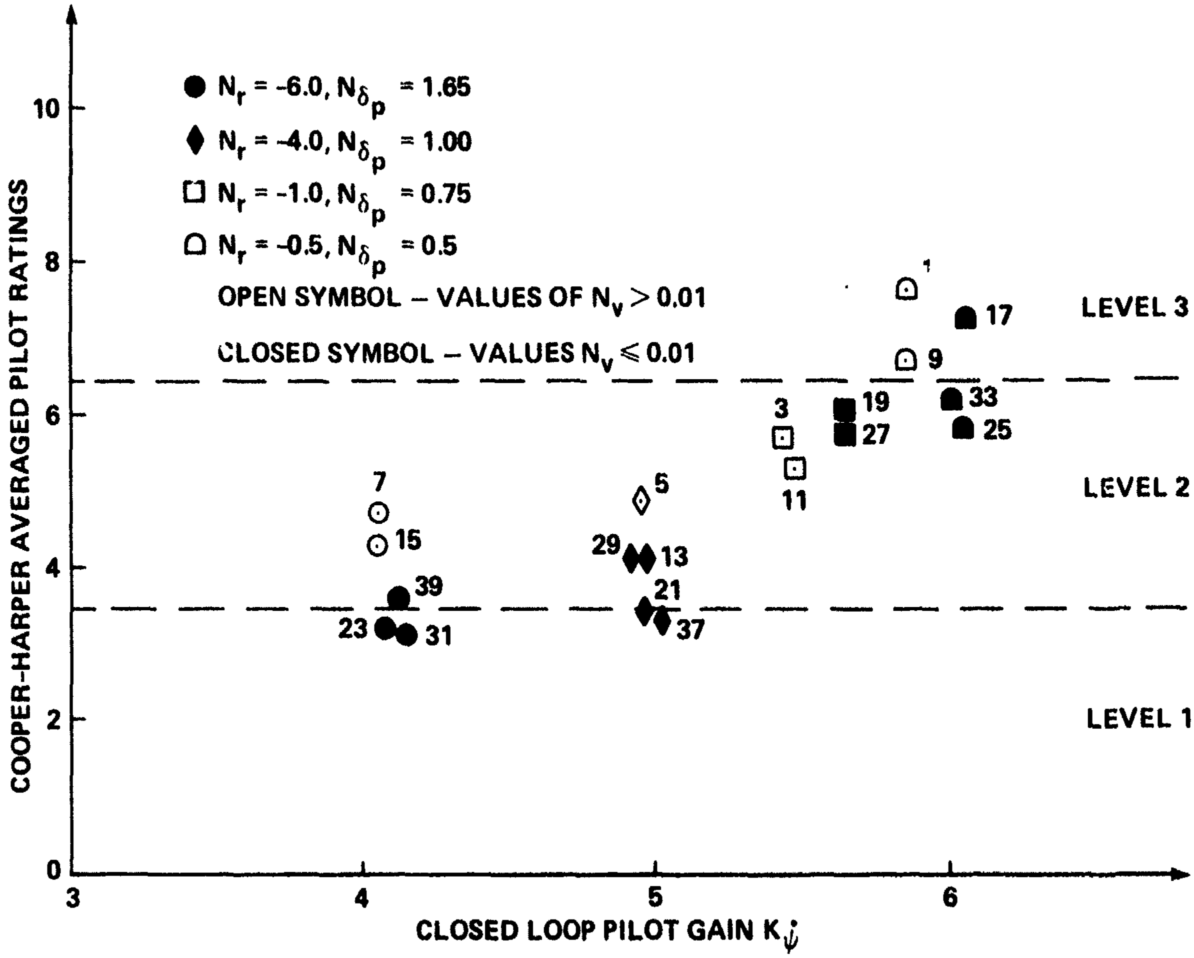


Figure 32.- Pilot ratings versus closed-loop pilot gain ($K_{\dot{\psi}}$) for NOE task.

reference 33. There are at least two serious shortcomings of the performance approach. First, it is difficult to select one or two performance measures that have predictive validity with reference to ultimate mission success. Secondly, the pilot tends to accommodate his output to a wide range of variations in control parameters without permitting degradation of vehicle performance. Reference 33 states that this accommodation is accomplished by a shift of effort and attention to the control task, at the expense of operator readiness for unexpected contingencies of the mission. This method was explored using data and performance measures from the yaw control experiment's primary test configurations.

<u>Analysis of variance</u>- The performance measures selected for an analysis of variance examination during the experiment were:

Height above ground level - NOE task (1)
Forward airspeed - NOE task (1)
Heading changes - deceleration task (2)
Yaw rates - in-ground-effect hover turn (3)
Height above ground level - IGE turn (3)
Heading error - hover bob-up (4)
Yaw rates - OGE hover turn (5)
Height above ground level - OGE turn (5)
Reaction time data - fire control task (6)

These measures were selected by the researchers on an arbitrary basis. A task analysis was conducted, and standards used in reference 19 to perform the listed combat task were utilized as a reference for the various measures.

Table 8 lists the analysis of variance results for each of the performance measures. The F-test indicated differences in level of performance for the following measures (significant difference indicated if $p \leq 0.05$):

Forward airspeed (task 1) due to differences in configuration or turbulence
Aircraft heading (task 2) due to the combination of differences in configuration and turbulence
Yaw rates (task 3) due to differences in configuration
Yaw rates (task 5) due to differences in configuration

The F-test did not indicate which of the configurations differed significantly in performance from other configurations. To establish the differences and the meaningfulness of each of the above measures, a further analysis was conducted of each of the above.

Forward airspeed performance measure. The mean forward airspeed versus damping is depicted in figure 33. Also for each data point, the associated pilot rating is included. The pilots were instructed to fly at 40 knots ±5 knots in flying the NOE corridor. It can be seen that in none of the turbulence cases was the pilot able to stay within the performance criteria. Also, the ratings for the turbulence cases do not approach level 1 handling qualities.

The cases that did meet the performance criteria are divided into two groups. Those two groups were: the configurations that met level 1 handling qualities criteria ($|N_r| \geq 2.5$); and those configurations that remained outside level 1 ($|N_r| \leq 2.5$) in the level 2 handling qualities criteria area. The pilot comments show that most of the configurations that did meet the performance criteria (but not level 1 handling qualities) just required more pilot compensation to adequately perform the task. This caused the degradation in the pilot ratings. In this experiment the pilot was not required to perform other tasks such as navigation and communication that might impinge on his ability to compensate for poorer configurations. It does appear that forward airspeed can be used as a good performance measure for NOE flight. However, the total task must be structured so that it encompasses all necessary actions a pilot must cognitively perform manually, perceptively, and communicatively. This would ensure that a performance measure is met

TABLE 8.- ANALYSIS OF VARIANCE FOR NOE PERFORMANCE MEASURES

Variable	Degrees of freedom	Mean square	F statistic	Probability
Height above ground level - task 1				
Configuration	10	15.44	1.19	0.33
Turbulence	1	48.1	3.22	.17
Configuration × turbulence	10	9.1	.54	.85
Forward airspeed - task 1				
Configuration	10	15.2	2.31	0.0375
Turbulence	1	2503.5	88.9	.0025
Configuration × turbulence	10	7.31	.72	.6985
Aircraft heading - task 2				
Configuration	10	29.6	1.94	0.078
Turbulence	1	17.9	.43	.56
Configuration × turbulence	10	24.1	2.66	.019
Yaw rates - task 3				
Configuration	10	15.35	4.77	0.0004
Turbulence	1	.47	.09	.783
Configuration × turbulence	10	1.79	.81	.62
Height above ground level - task 3				
Configuration	10	2.99	1.37	0.2424
Turbulence	1	.80	.04	.85
Configuration × turbulence	10	2.14	.92	.53

Level of significance $p \leq 0.05$.

TABLE 8.- Concluded

Variable	Degrees of freedom	Mean square	F statistic	Probability
Heading error - task 4				
Configuration	10	15.07	0.8	0.63
Turbulence	1	6.8	4.32	.13
Configuration × turbulence	10	17.5	1.04	.4332
Yaw rate - task 5				
Configuration	10	11.8	3.90	0.0018
Turbulence	1	.20	.08	.8
Configuration × turbulence	10	3.1	1.15	.36
Height above ground level - task 5				
Configuration	10	18.0	1.14	0.366
Turbulence	1	18.7	5.23	.11
Configuration × turbulence	10	23.14	1.67	.1349
Reaction time - task 6				
Configuration	10	2.6	1.49	0.193
Turbulence	1	.0009	.02	.893
Configuration × turbulence	10	1.59	1.21	.3234

because of overall good handling qualities and not just because of added pilot compensation.

Aircraft heading error performance measure. Aircraft configuration (represented by values of yaw damping) versus aircraft heading error is represented in figure 34. During this task the pilot was instructed to maintain the aircraft heading at 360° ±5°. It can be observed that most of the configurations performed within the performance criteria, even with turbulence. It can be concluded that the task performance standard was not set at a level where the lack of good handling qualities really made a considerable difference. If the data in figure 34 were to be given a performance criterion of ±3° instead of the ±5°, then the standard could possibly have some significance regarding handling qualities. Minimum damping

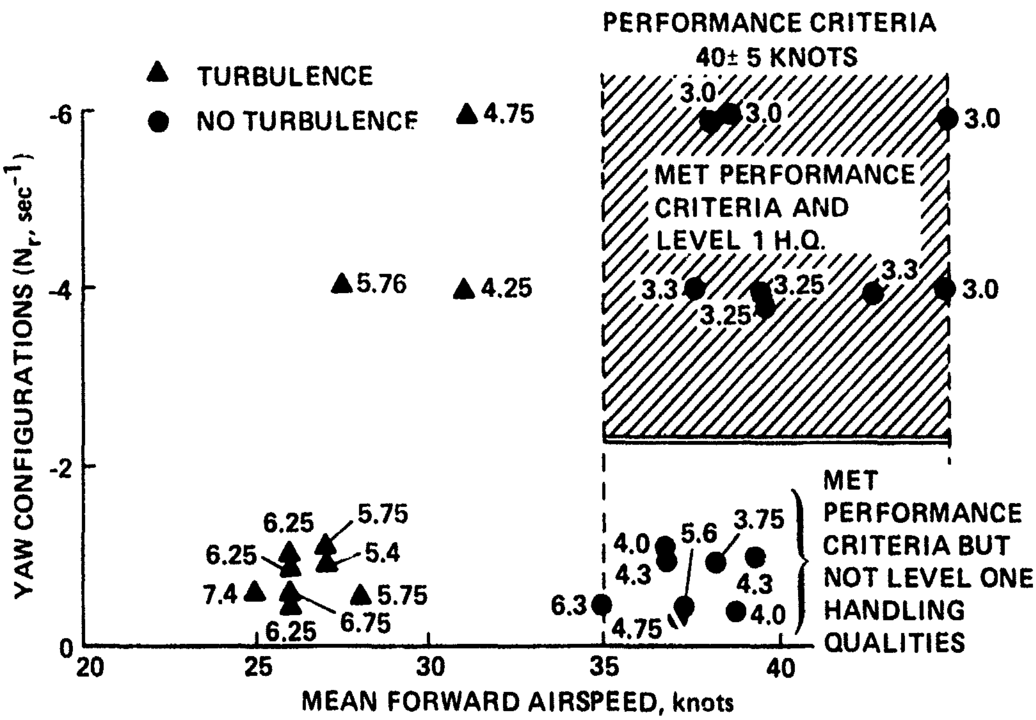


Figure 33.- NOE task performance measure data.

values could then be specified that met both the performance criteria and the level 1 handling qualities. Still, there would be cases that do not meet level 1 handling qualities criteria, but do meet the revised performance standard. This again illustrates the pilot's ability to compensate for poorer handling qualities, which further substantiates the conclusion that performance data cannot be used solely in determining the "goodness" of an aircraft.

Yaw rate performance measure (tasks 3 and 5). The performance data for all the configurations show the minimum yaw rate achieved was 8°/sec and the maximum rate was 12°/sec. The pilots were only instructed to maintain a yaw rate of less than 22°/sec for both hover tasks, and all of the configurations were well within the criteria limits. Even though differences in performance caused by changes in configuration were statistically evident, it was concluded that the overall difference in yaw rates was not significant. In this case the relative performance criterion was not set at a precise level in the context of the measured data.

Fire-control task performance analysis. With Army doctrine currently emphasizing air-to-air combat for helicopters, the ability of the aircraft weapon system to accomplish this task in an NOE environment takes on special significance.

Because there is presently no operational air-to-air system from which to gain performance data, several questions become apparent. Can an aircraft at hover engage a moving air target with a stinger-type missile system? If it can, what are the performance standards for this type of task?

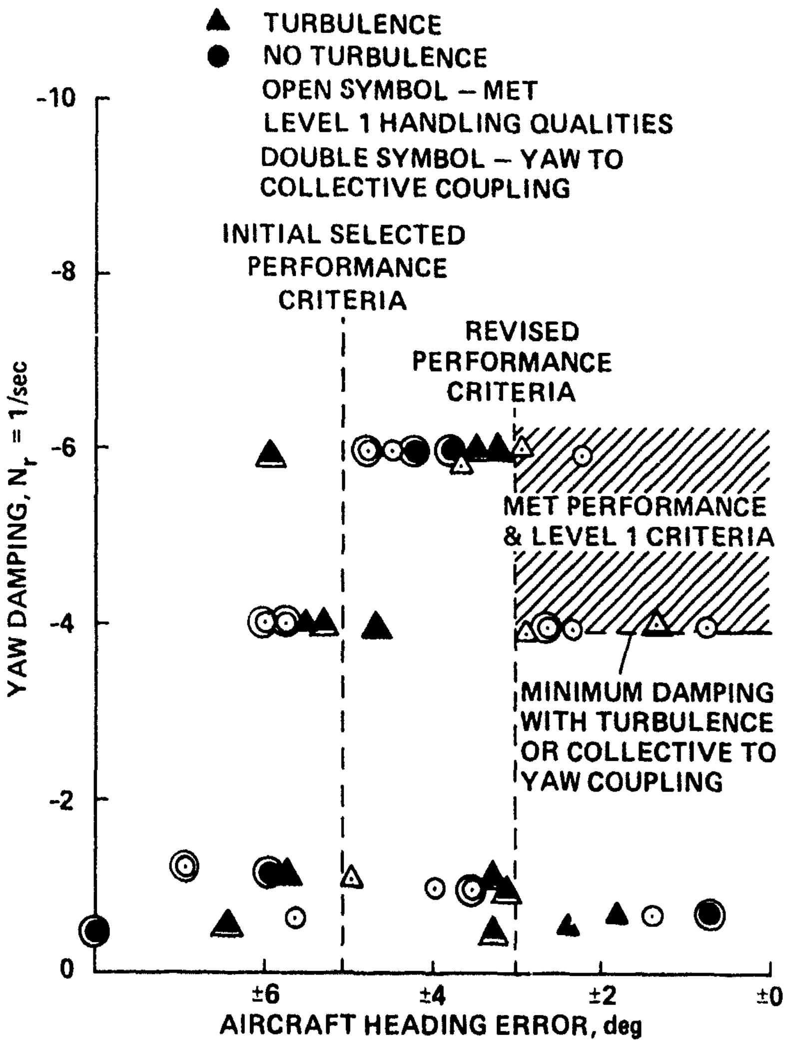


Figure 34.- Deceleration task performance measure data.

Performance data were collected during the simulation of the fire control task to obtain information that could possibly be used in assessing preliminary aircraft system designs. A complete tabulation of the performance data collected is shown in appendix K. The data consisted of: the average successes, reaction time data, circular error radius data, maximum yaw rates, successful-firing-time data, and mean yaw rates. These measures were selected due to their importance in the overall performance of the fire control task.

Target engagement success rate. In figure 35 the region of success ≥75% is plotted on the N_r versus $\dot{\psi}$ graph. Also illustrated is the level 1 handling qualities boundary. A success was defined as: when the piloted aircraft was able to acquire and shoot down the target aircraft within the allotted time without ascending above 100 ft or crashing into the surrounding terrain.

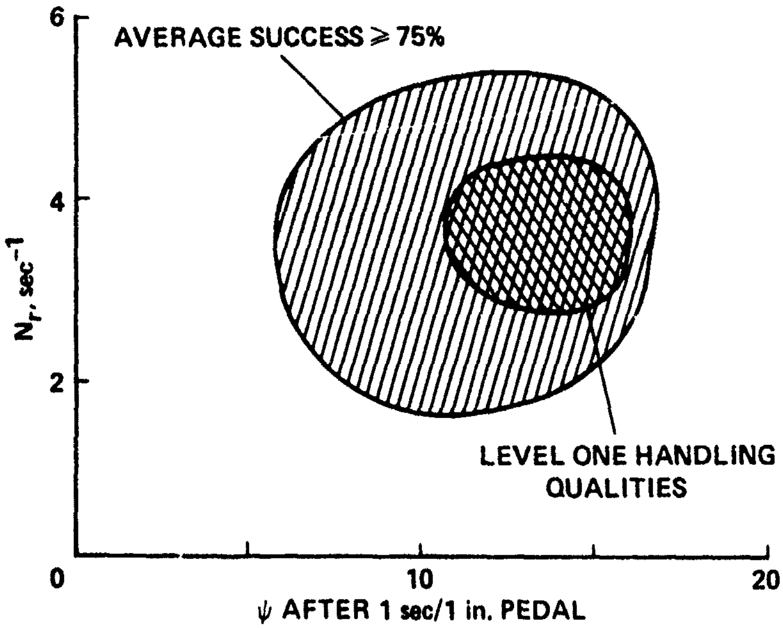


Figure 35.- Fire control task performance measure data.

The graph illustrates that the level 1 handling qualities boundary is encompassed by the area of high success, but there are regions where high success dates occurred that lie outside the level 1 handling qualities boundary. The data emphasize previous performance results that show the pilot can still maintain adequate performance by increasing pilot compensation to a moderate or considerable extent. The success rate can be used to determine overall adequacy of the system, but it must be analyzed in context of total pilot effort expended to complete all aspects of the task.

Task peculiar performance data. The performance data listed in table 9 did not correlate with any specific configuration parameter, but it was considered important

TABLE 9.- TASK PERFORMANCE DATA (AIR-TO-AIR TARGET ACQUISITION)

	Average for 4 pilots	Highest average value observed	Maximum value observed	Minimum value observed
Maximum yaw rates (during acquisition)	25.7°/sec	32.2° sec	37°/sec	10.5°/sec
Pilot reaction time	2.1 sec	3.7 sec	6.4 sec	.043 sec
Circular error radius	8.86 ft	13.3 ft	34 ft	2 ft
Successful firing time	9.2 sec	10.37 sec	12.64 sec	5.94 sec
Yaw acceleration	5.5°/sec^2	6.6°/sec^2	9.7°/sec^2	1.03°/sec^2
Mean yaw rate	5.38°/sec	6.16°/sec	8.4°/sec	2.99°sec

because it outlined the overall performance of the pilot-aircraft system in accomplishing this particular task. The data in effect could be an initial attempt at producing an aircraft performance criterion for conducting the air-to-air engagement task from a hover.

CONCLUSIONS

A piloted simulation was conducted to investigate directional-axis handling-qualities requirements for low speed (≤40 knots) and hover tasks performed by an advanced Scout/Attack helicopter. The various test configurations included directional characteristics of various candidate light helicopter family configurations. A secondary objective of this investigation was to model the first-order effects that contribute to the loss of tail rotor control experienced by the OH-58 series aircraft and also to evaluate the handling qualities parameters that reduce or eliminate tail rotor control problems in the context of the given test conditions. Based on the results of the experiment, the following conclusions were drawn:

1. Subjective ratings are a reliable method of determining the handling qualities of piloted aircraft. By using the analysis of variance technique, Cooper-Harper pilot ratings were utilized to ascertain subjective differences in configuration, turbulence, and task; the establishment of which led to further meaningful analysis of the results.

2. Higher values of directional gust sensitivity required greater minimum values of yaw damping to achieve level 1 handling qualities for nap-of-the-Earth (NOE) flight, NOE deceleration, and hover turns. Not only are minimum yaw damping levels affected by changes in weathercock stability (N_v), but the variation in task and the addition of turbulence will also cause a shift in required damping levels. Typical values of required damping for three tasks with turbulence (T) and without turbulence (NT) are:

	N_v	NOE	Deceleration	Hover turns
T	0.005 .02	$N_r \le -4.0$ Level 1 [not achieved]	$N_r \le -4.0$ Level 1 [not achieved]	$N_r \le -6.0$ Level 1 [not achieved]
NT	0.005 .02	$-1 > N_r \ge -4.5$ $-3 > N_r \ge -6.0$	$N_r < -0.5$ $N_r < -1.0$	$N_r < -2.0$ $N_r < -6.0$

3. Yaw damping, yaw gust sensitivity, and control sensitivity cannot be used as total criteria for an air-to-air target acquisition and tracking task. Control response criteria must also be applied. Values of N_r between -3 and -4 (sec^{-1}) and a heading response of 10° to 16° in 1 sec for 1 in. of pedal input yielded level 1 handling qualities.

4. Open-loop aircraft turbulence response appears to be a satisfactory criterion for determining aircraft handling qualities at hover. For the hover task with low turbulence/wind, the level 1 handling qualities criterion was 1.6° (σ_T). Two important factors must be recognized as affecting this value: one is the level of turbulence/wind selected, and the other is the time allowed for the σ_T value to be generated.

5. For the tail rotor configurations, a relatively simple tail rotor model was able to reproduce the reductions in yaw damping and control power at certain relative wind azimuths which contribute to a loss of directional control. Loss of directional control occurred only for tailwinds and quartering tailwinds greater than 20 knots for the specified NOE flight task. For wind speeds greater than 20 knots, configurations with larger values of yaw damping ($|N_r| > 1.0\ sec^{-1}$) were less susceptible to a loss of directional control; for winds greater than 30 knots, lower values of weathercock stability ($N_v < 0.01$) also had beneficial effects. The effects of this particular engine model did not induce or aggravate the loss of tail rotor control substantially for the given test conditions and variables.

6. It appears that minimum bandwidths may be specified, in general, for some tasks. But other aircraft parameters should also be used for the definition of any particular criteria. This applies to the NOE, deceleration, and hover tasks. For these tasks, configurations with bandwidths less than 3 rad/sec will assuredly have poor handling qualities; but on the other hand, just because a configuration exhibits a bandwidth greater than 3 rad/sec does not ensure that it will be a level 1 configuration. There are other factors such as the task, the control strategy, inter-axis coupling, and turbulence levels that must be accounted for. Because of the uniqueness of the air-to-air tracking task, it is necessary to optimize pedal response with yaw damping for the specific task. Using only the bandwidth criteria may not yield totally reliable results. Finally, a simple pilot model can be used to provide a preliminary predictive capability. This analytic approach can be considered ideal from the system design point of view because the optimization of a system with reference to handling qualities can be begun on paper in the very early phases of control design.

7. The performance data for the yaw control experiment yielded an objective record of measures as a function of the variation in vehicle, task, and turbulence parameters. The performance measures that were found to have a predictive validity with reference to mission success were: airspeed, for the NOE flight; heading error, for the deceleration maneuver; and target engagement success rate, for the fire control task. The values of these measures were:

Airspeed - 40 knots ±5 knots
Yaw heading error ±5° (initially), ±3° (revised)
Target engagement success rate ≥ 75%

In using performance measures alone, one must be careful in equating them to handling qualities. As shown in the performance measures results, the controller tends to accommodate his output to a wide range of variations in control parameters without permitting degradation of vehicle performance. Therefore, performance measures must be used in conjunction with handling qualities assessment to ensure that the aircraft performs the mission with the desired level of effort. Finally, for performance measures to have some predictive validity they must be carefully chosen so they reference the success of the task. This can only be accomplished by conducting a thorough task analysis and deriving specific and significant standards for the given task.

APPENDIX A

SCAT CONFIGURATION PARAMETERS AND STABILITY DERIVATIVES

SCAT AERODYNAMICS

General

The total aerodynamic forces and moments required for the six-degree-of-freedom equations of motion are generated as the summation of reference and first-order terms of a Taylor series expansion about a reference trajectory defined as a function of airspeed (VEQ). Function generation system subroutines are utilized to produce the values for the following parameters as functions of a single variable VEQ:

1. Reference values for total forces and moments--X_R, Y_R, Z_R, and M_R
2. Reference values for aircraft motion and control variables--w_R, $A_{1_{S_R}}$, $B_{1_{S_R}}$, θ_{o_R}, and θ_{TR_R}
3. Values for the aircraft stability and control parameters--e.g., X_w and Z_{θ_o}
4. Values for engine/rotor degree-of-freedom--e.g., Z_Ω, N_Ω

The reference values for the total forces and moments are specified at 20-knot intervals of the independent variable for 20 knots ≤ VEQ ≤ 100 knots. Each of the remaining dependent variables is specified at 20-knot intervals (above 20 knots) and at 10-knot intervals (from 0 to 20 knots of the independent variable). Linear interpolation is used to determine the value of each parameter between these breakpoints.

Derivatives

The longitudinal and lateral-directional aerodynamics of the basic model are uncoupled with the exception of yawing moment due to tail rotor collective pitch inputs. An option which adds perturbations to the basic aerodynamic forces and moments to account for coupling effects is available. The following coupling effects are included: (1) longitudinal equations, v_a, p, r, A_{1_S}, θ_{TR}, Ω, and (2) lateral-directional equations, w, q, θ_o, B_{1_S}, Ω.

Summary of Equations

Perturbation variables-

$$DWB = WB - WBR$$

$$DTHET\emptyset = THET\emptyset - THET\emptyset R$$

$$DA1S = A1S - A1SR$$

$$DB1S = B1S - B1SR$$

$$DTHETTR = THETTR - THETTRR$$

$$DOMEGA = OMEGA - OMEGAR$$

where WBR, THETØR, A1SR, B1SR, THETTR are all generated by function generator system subroutines as functions of VEQ. OMEGAR is set at a constant equal to the normal rotor operating speed.

X-force equation-

$$FAX = XMASS*(XQ*QB + XW*DWB + XB1S*DB1S + XTH\emptyset*DTHET\emptyset + XREF)$$

where XQ, XW, XB1S, XTHØ, XHSIA, and XREF are all generated as functions of VEQ

Y-force equation-

$$FAY = XMASS*(YP*PB + YR*RB + YV*RB + YA1S*DA1S + YTHTR*DTHETTR + YREF)$$

where YP, YR, YV, YA1S, YTHTR, and YREF are all generated as functions of VEQ

Z-force equation-

$$FAZ = XMASS*(ZQ*QB + ZW*DWB + ZB1S*DB1S + ZTH\emptyset*DTHET\emptyset + ZH*DH + ZREF)$$

where ZQ, ZW, ZB1S, ZTHØ, ZH, and ZREF are all generated as functions of VEQ and

$$DH = \begin{cases} HAGL - 40 & \text{for } HAGL \le 40 \text{ ft} \\ 0 & \text{for } HAGL > 40 \text{ ft} \end{cases}$$

where HAGL = HCG - HTER.

L-moment equation-

$$TAL = XIXX*(ULP*PB + ULR*RB + ULV*VB + ULA1S*DA1S + ULTTR*DTHETTR)$$

where ULP, ULR, ULV, ULA1S, and ULTTR are all generated as functions of VEQ.

M-moment equation-

TAM = XIYY*(UMQ*QB + UMW*DWB + UMB1S*DB1S + UMTHØ*DTHETØ + UMREF)

where UMQ, UMW, UMB1S, UMTHØ, and UMREF are all generated as functions of VEQ.

N-moment equation-

TAN = XIZZ*(UNP*PB + UNR*RB + UNV*VB + UNTHØ*DTHETØ + UNTTR*DTHETTR + UNA1S*DA1S)

where UNP, UNR, UNV, UNTHØ, UNTTR, and UNA1S are all generated as functions of VEQ.

The values of the referenced forces and moments, stability and control parameters, and reference aircraft motion and control variables are presented in tables A-1 through A-8 as functions of (VEQ) at the designated breakpoints.

The optional perturbations to the basic expressions for total aerodynamic forces and moments to account for coupling effects are as follows:

DELFAX = XMASS*(UXP*PB + UXR*RB + UXV*VB + XA1S*DA1S + XTHTR*DTHETTR)

DELFAY = XMASS*(UYQ*QB + UYW*DWB + YB1S*DB1S + YTHØ*DTHETØ)

DELFAZ = XMASS*(UZP*PB + UZR*RB + UZV*VB + ZA1S*DA1S + ZTHTR*DTHETTR
+ ZOMEGA*DOMEGA)

DELTAL = XIXX*(ULQ*QB + ULW*DWB + ULB1S*DB1S + ULTHØ*DTHETØ)

DELTAM = XIYY*(UMP*PB + UMR*RB + UMV*VB + UMA1S*DA1S + UMTTR*DTHETTR)

DELTAN = XIZZ*(UNQ*QB + UNW*DWB + UNB1S*DB1S + NOMEGA*DOMEGA)

The values for the derivatives are also presented in tables A-3 through A-8.

Tail rotor modeling- For military applications, adequate directional control must be provided in hover and at low speeds in winds coming from any azimuth. To investigate this aspect, changes in tail rotor control power, aircraft yaw damping, N_r, and aircraft yaw gust sensitivity for winds coming from any azimuth was modeled by making both N_r and N_{δ_p} functions of relative wind direction and magnitude and by making N_v a function of wind magnitude.

The ARMCOP model in reference 22 was utilized to obtain the linear derivatives for N_r and N_{δ_p} from 0° to 360° (in 20° increments) for 0 to 40 knots (in 10-knot increments) (tables A-9 and A-10).

The tail rotor was modeled as a teetering rotor without cyclic pitch. Since the tail rotor flapping frequency was much higher than that of the main rotor system, the tip-path plane dynamics were neglected. The local flow at the tail rotor included the effect of downwash from the main rotor system. A complete description of the mathematical model is given in reference 22. A listing of the values for the tail rotor parameters is given in table A-11.

TABLE A-1.- MASS AND GEOMETRY CONSTANTS

Programming symbol	Engineering symbol	Definition	Units	Nominal value
XIXX	I_{xx}	Body axis moments	Slug-ft^2	1028.4
XIYY	I_{yy}	of inertia		2938.9
XIZZ	I_{zz}			2228.0
XIXZ	I_{xz}	Cross-product of inertia	Slug-ft^2	363.0
XMASS	M	Aircraft mass	Slugs	122.51
XP		Pilots design	Ft	+5.375
YP		eye position in		.93
ZP		body axis coordinates		-5.28

TABLE A-2.- REFERENCE TRAJECTORY PARAMETERS, FORCES, AND MOMENTS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
WR, ft/sec	w_R			3.97	3.65	6.56	6.29	5.36
A1SR, deg	$A_{1_{SR}}$	-0.51	-2.06	-2.678	-1.854	-1.23	-.824	-.1
B1SR, deg	$B_{1_{SR}}$	-.715	-.357	-.143	.286	.572	.6435	1.6
THETØR, deg	θ_{oR}	6.0	5.7	5.25	5.1	5.25	5.55	6.0
THETTRR, deg	θ_{TR_r}	9.225	8.61	7.38	6.15	5.53	4.61	5.75
XREF, ft/sec	X_R	2.913	3.633	3.633	1.893	2.142	1.392	.872
YR, ft/sec	Y_R	1.444	1.412	1.412	.8192	.6561	.6736	.9660
ZREF, ft/sec	Z_R	-32.036	-33.013	-33.013	-31.819	-31.963	-31.386	-31.878
UMREF, rad/sec	M_R	0	-.203	-.203	-.0135	-.0331	-.0105	-.0006

TABLE A-3.- X-FORCE STABILITY AND CONTROL PARAMETERS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
XQ, ft/sec^2/rad/sec	X_q	1.03	1.07	1.19	1.42	1.43	1.29	1.29
XU,* ft/sec^2/ft/sec	X_U	-.0144	-.021	-.025	-.024	.043	-.055	-.073
XW, ft/sec^2/ft/sec	X_W	.0194	.0236	.0319	.0396	.041	.045	.046
XTHØ, ft/sec^2/deg	X_{θ_O}	.332	.308	.285	.253	.257	.213	.077
XB1S, ft/sec^2/deg	X_{B1S}	.51	.5	.48	.46	.43	.41	.42
UXP, ft/sec^2/rad/sec	X_P	-.197	-.188	-.16	-.133	-.152	-.21	-.35
UXR, ft/sec^2/rad/sec	X_r	-.04	-.034	-.04	-.066	-.042	-.03	-.04
UXV, ft/sec^2/ft/sec	X_v	.004	.004	.0043	.0067	.005	.0046	.007
XA1S ft/sec^2/deg	X_{A1S}	-.147	-.146	-.146	-.146	-.139	-.133	-.119
XTHTR ft/sec^2/deg	$X_{\theta TR}$	-.00024	-.002	-.0015	-.005	-.007	-.016	-.03
XOMEGA	X_Ω	0	0	0	0	0	0	0

*Not explicitly included in aerodynamics.

TABLE A-4.- Y-FORCE STABILITY AND CONTROL PARAMETERS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
YP, ft/sec^2/rad/sec	Y_p	-0.9	-1.1	-1.24	-1.45	-1.46	-1.28	-0.77
YR, ft/sec^2/ft/sec	Y_r	.3	.29	.33	.63	.914	1.17	1.52
YV, ft/sec^2/ft/sec	Y_v	-.033	-.032	-.033	-.08	-.107	-.135	-.175
YA1S ft/sec^2/deg	Y_{A1S}	.5	.5	.49	.49	.496	.5	.524
YTHTR, ft/sec^2/deg	$Y_{\theta tr}$	.239	.235	.226	.217	.206	.226	.24
UYQ, ft/sec^2/rad/sec	Y_q	-.243	-.048	-.045	.072	.048	.036	.017
UYW, ft/sec^2/rad/sec	Y_w	-.005	-.0117	-.01	-.013	-.023	-.033	-.049
YB1S, ft/sec^2/ft/sec	Y_{B1S}	.15	.15	.155	.165	.165	.170	.189
YTHØ, ft/sec^2/deg	Y_{θ_o}	.104	.105	.016	-.023	-.053	-.08	-.109
YOMEGA	Y_Ω	0	0	0	0	0	0	0
YU, ft/sec^2/ft/sec	Y_u	.0075	.0018	.0035	.00403	-.006	.0012	.0026

TABLE A-5.- Z-FORCE STABILITY AND CONTROL PARAMETERS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
ZQ, ft/sec^2/rad/sec	Z_q	-0.028	0.126	0.854	0.47	0.12	0.54	0.087
ZOMEGA, ft/sec	Z_Ω	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52	-2.52
ZU*, ft/sec^2/ft/sec	Z_u	.0133	-.156	-.188	-.069	-.011	.021	.016
ZW, ft/sec^2/ft/sec	Z_w	-.32	-.384	-.5	-.65	-.73	-.73	-.81
ZTHØ, ft/sec^2/deg	Z_{θ_o}	-4.93	-4.8	-4.77	-5.29	-5.73	-6.2	-6.56
ZB1S, ft/sec^2/deg	Z_{B1S}	.06	.199	.35	.713	1.12	1.55	2.08
ZH, ft/sec^2/ft	Z_h	.47	.3525	.235	0	0	0	0
UZP, ft/sec^2/rad/sec	Z_p	-.023	.175	.23	.53	.85	1.2	1.53
UZR, ft/sec^2/ft/sec	Z_r	.209	.21	.213	.25	.289	.33	.348
UZV, ft/sec^2/ft/sec	Z_v	-.0006	-.002	-.0026	-.004	-.0056	-.0077	-.01
ZA1S, ft/sec^2/deg	Z_{A1S}	-.016	-.048	-.084	-.168	-.14	-.36	-.45
ZTHTR, ft/sec/deg	$Z_{\theta TR}$	.00013	.0012	.002	.004	.006	.01	.022

*Not explicitly included in aerodynamics.

TABLE A-6.- L-MOMENT STABILITY AND CONTROL PARAMETERS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
ULP, rad/sec^2/rad/sec	L_p	-3.03	-3.1	-3.21	-3.3	-3.3	-3.17	-2.83
ULR, rad/sec^2/rad/sec	L_r	-.114	-.113	-.106	-.013	-.072	-.17	-.33
ULV, rad/sec^2/ft/sec	L_v	-.026	-.025	-.024	-.03	-.03	-.032	-.031
ULA1S, rad/sec^2/deg	L_{A1S}	.92	.99	.92	.92	.92	.92	.937
ULTTR, rad/sec^2/deg	$L_{\theta TR}$	.067	.066	.064	.06	.055	.06	.0634
ULQ, rad/sec^2/rad/sec	L_q	-.738	-.73	-.71	-.7	-.65	-.65	-.642
ULW, rad/sec^2/ft/sec	L_w	-.0008	-.0007	-.0005	-.0007	-.0015	-.005	0.011
ULB1S, rad/sec^2/deg	L_{B1S}	-.315	-.315	-.315	-.32	-.32	-.325	-.34
ULTHØ, rad/sec^2/deg	L_{θ_o}	-.0[illegible]	-.07	-.076	-.09	-.09	-.12	-.213
UOMEGA, 1/sec	L_Ω	0	0	0	0	0	0	0
ULU, rad/sec^2/ft/sec	L_u	.026	.0184	.0085	.003	-.007	-.005	-.003

TABLE A-7.- M-MOMENT STABILITY AND CONTROL PARAMETERS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
UMQ, rad/sec^2/rad/sec	M_q	-1.18	-1.2	-1.25	-1.22	-1.24	-0.91	-1.1
UMU, rad/sec^2/ft/sec	M_u	.0074	.0074	.0067	.0061	.0045	.009	.0051
UMW rad/sec^2/ft/sec	M_w	-.0046	-.0064	-.0088	.0029	.004	.031	.0184
UMTHØ, rad/sec^2/deg	M_{θ_o}	-.043	-.029	-.013	.005	.046	.04	.12
UMB1S, rad/sec^2/deg	M_{B1S}	-.33	-.33	-.327	-.324	-.328	-.32	-.338
UMP, rad/sec^2/rad/sec	M_p	.257	.255	.246	.232	.225	.24	.24
UMR, rad/sec^2/ft/sec	M_r	-.005	-.0026	.0006	.0084	.0078	.0134	.0281
UMA1S, rad/sec^2/deg	M_{A1S}	.108	.108	.108	.108	.11	.108	.108
UMTTR, rad/sec^2/deg	$M_{\theta TR}$	-.003	-.0015	-.0004	.0013	.0048	.009	.02
MOMEGA, 1/sec	M_Ω	0	0	0	0	0	0	0
UMV, rad/sec^2/ft/sec	M_v	-.0025	-.0025	-.0025	-.003	-.0028	-.003	-.0046

TABLE A-8.- N-MOMENT STABILITY AND CONTROL PARAMETERS

Programming symbol	Engineering symbol	VEQ, knots						
		0	10	20	40	60	80	100
UNP, rad/sec^2/rad/sec	N_p	-0.09	-0.126	-0.144	-0.179	-0.225	-0.3	-0.48
UNR, rad/sec^2/rad/sec	N_r	-.43	-.48	-.55	-.83	-1.14	-1.40	-1.77
UNV, rad/sec^2/ft/sec	N_v	.018	.019	.022	.027	.031	.036	.078
UNTRØ, rad/sec^2/deg	N_{θ_o}	.324	.3	.26	.198	.186	.2	.35
UNA1S, rad/sec^2/deg	N_{A1S}	.03	.03	.03	.02	.016	.015	.025
UNTTR, rad/sec^2/deg	$N_{\theta TR}$	-.268	-.265	-.253	-.248	-.232	-.265	-.27
UNQ, rad/sec^2/ft/sec	N_q	-.21	-.216	-.24	-.262	-.36	-.455	-.599
UNW, rad/sec^2/deg	N_w	-.002	-.004	-.009	-.021	-.02	-.015	-.005
UNB1S, rad/sec^2/deg	N_{B1S}	-.01	-.012	-.015	-.028	-.39	-.04	-.005
NOMEGA, 1/sec	N_Ω	.062	.062	.062	.062	.062	.062	.062
UNU, rad/sec^2/ft sec	N_u	.005	.0008	-.016	-.0105	-.00813	-.0084	-.008

TABLE A-9.- N_{δ_p} DERIVATIVE VALUES FOR LINEAR TAIL-ROTOR MODELING

$\beta_{wind/direction}$ (GAMAHIC), deg										
VEQ	0	20	40	60	80	90	100	120	140	160
10	N10	N10	N10	N10 × 100.7%	N10 × 100.7%	N10 × 100.7%	N10 × 100.7%	N10	N10	N10 × 99.6%
20	N20	N20	N20 × 103.5%	N20 × 104.6%	N20 × 105%	N20 × 105%	N20 × 104.6%	N20 × 104.6%	N20 × 103%	N20 × 102%
30	N30	N30 × 105%	N30 × 107%	N30 × 107%	N30 × 106%	N30 × 107%	N30 × 107%	N30 × 107%	N30 × 107%	N30 × 104%
40	N40	N40 × 125%	N40 × 127%	N40 × 126%	N40 × 124%	N40 × 125%	N40 × 128%	N40 × 127%	N40 × 126%	N40 × 125%
VEQ		180	200	220	240	260	280	300	320	340
10		N10 × 99.6%	N10 × 99.6%	N10 × 99.6%	N10	N10 × 100.7%	N10 × 101%	N10 × 99.6%	N10 × 100.7%	N10
20		N20 × 99%	N20 × 97.6%	N20 × 96.7%	N20 × 101%	N20 × 106%	N20 × 108%	N20 × 102%	N20 × 97.7%	N20 × 97.7%
30		N30	N30 × 101%	N30 × 65%	N30 × 69%	N30 × 107%	N30 × 109%	N30 × 75%	N30 × 66%	N30 × 78%
40		N40 × 120%	N40 × 91.5%	N40 × 95%	N40 × 70%	N40 × 53%	N40 × 118%	N40 × 56%	N40 × 93.3%	N40 × 131%

N10 = $N_{\theta TR}$ at 10 knots VEQ
N20 = $N_{\theta TR}$ at 20 knots VEQ
N30 = $N_{\theta TR}$ at 30 knots VEQ
N40 = $N_{\theta TR}$ at 40 knots VEQ

TABLE A-10.- N_r DERIVATIVE VALUES FOR LINEAR TAIL-ROTOR MODELING

$\beta_{wind/direction}$ (GAMAHIC), deg										
VEQ	0	20	40	60	80	90	100	120	140	160
10	R10	R10 × 105%	R10 × 105%	R10 × 105%	R10 × 110%	R10 × 108%	R10 × 108%	R10 × 104%	R10	R10 × 96%
20	R20	R20 × 102%	R20 × 103%	R20 × 105%	R20 × 110%	R20 × 110%	R20 × 110%	R20 × 102%	R20 × 95%	R20 × 90%
30	R30	R30 × 101%	R30 × 103%	R30 × 103%	R30 × 109%	R30 × 113%	R30 × 110%	R30 × 101%	R30 × 94%	R30 × 89.7%
40	R40	R40 × 80%	R40 × 82%	R40 × 82%	R40 × 82%	R40 × 92%	R40 × 87%	R40 × 80%	R40 × 73%	R40 × 69%
VEQ		180	200	220	240	260	280	300	320	340
10		R10 × 94%	R10 × 91%	R10 × 91%	R10 × 91%	R10 × 91%	R10 × 92%	R10 × 91%	R10	R10
20		R20 × 86%	R20 × 81%	R20 × 75%	R20 × 68%	R20 × 68%	R20 × 71%	R20 × 76%	R20 × 86%	R20 × 95%
30		R30 × 87%	R30 × 79%	R30 × 95.5%	R30 × 70.5%	R30 × 45.5%	R30 × 51%	R30 × 75%	R30 × 106%	R30
40		R40 × 68%	R40 × 89%	R40 × 79%	R40 × 80%	R40 × 97%	R40 × 89%	R40 × 85%	R40 × 82%	R40

R10 = N_r at 10 knots VEQ
R20 = N_r at 20 knots VEQ
R30 = N_r at 30 knots VEQ
R40 = N_r at 40 knots VEQ

TABLE A-11.- SCAT CONFIGURATION DESCRIPTION REQUIREMENTS (UTILIZING ARMCOP MODEL PARAMETERS)

Name	Algebraic symbol	Computer mnemonic	Units	Example value
<u>Main rotor (MR) group</u>				
MR rotor radius	R_{MR}	ROTOR	ft	17.5
MR chord	c_{Mr}	CHORD	ft	.79
MR rotational speed	Ω_{MR}	OMEGA	rad/sec	41.3
Number of blades	nb	BLADES	N-D	4
MR Lock number	γ_{MR}	GAMMA	N-D	7.06
MR hinge offset	ε	EPSLN	%/100	.0291
MR flapping spring constant	K_{β}	AKBETA	lb-ft/rad	11287.46
MR pitch-flap coupling tangent of δ_3	K_1	AKONE	N-D	.4307
MR blade twist	θt_{MR}	THETT	rad	-.17
MR precone angle (required for teetering rotor)	$a_{o_{MR}}$	AOP	rad	.034907
MR solidity	σ_{MR}	SIGMA	N-D	.05794
MR lift curve slope	a_{MR}	ASLOPE	rad^{-1}	6.00
MR maximum thrust	$C_{T_{max}}$	CTM	N-D	.1145
MR longitudinal shaft tilt (positive forward)	i_s	CIS	rad	.08726
MR hub stationline	STA_H	STAH	in.	107.329
MR hub waterline	WL_H	WLH	in.	115.3
<u>Tail rotor (TR) group</u>				
TR radius	R_{TR}	RTR	ft	2.7083
TR rotational speed	Ω_{TR}	OMTR	rad/sec	249.338
TR Lock number	γ_{TR}	GAMATR	N-D	1.79
TR solidity	σ_{TR}	STR	N-D	.1244
TR pitch-flap coupling tangent	$K_{1_{TR}}$	FLOTR	N-D	-.5774
TR precone	$a_{o_{TR}}$	AOTR	rad	.01745
TR blade twist	θt_{TR}	THETR	rad	0
TR lift curve slope	a_{TR}	ATR	rad^{-1}	5.73
TR hub stationline	STA_{TR}	STATR	in.	354.104
TR hub waterline	WL_{TR}	WLTR	in.	88.067

TABLE A-11.- CONTINUED

Name	Algebraic symbol	Computer mnemonic	Units	Example value
Horizontal stabilizer (HS)				
HS station	STA_{HS}	STAHS	in.	258.12
HS waterline	WL_{HS}	WLHS	in.	72.94
HS incidence angle	i_{HS}	AIHS	rad	-.091
HS area	S_{HS}	SHS	ft^2	9.74
HS aspect ratio	AR_{HS}	ARHS	N-D	4.33
HS maximum lift curve slope	$CL_{max_{HS}}$	CLMHS	N-D	.674
HS dynamic pressure ratio	η_{HS}	XHG	N-D	.77 - .85
Main rotor induced velocity effect at HS	$K_{V_{MR}}$	XKVMR	N-D	1.0
Vertical fin (VF)				
VF stationline	STA_{VF}	STAVF	in.	354.67
VF waterline	WL_{VF}	WLVF	in.	93.2
VF incidence angle	i_{VF}	AIFF	rad	-.091
VF area	S_{VF}	SF	ft^2	9.12
VF aspect ratio	AR_{VF}	ARF	N-D	4.60
VF sweep angle	Λ_F	ALMF	rad	.4538
VF maximum lift curve slope	$CL_{max_{VF}}$	CLMF	N-D	.77
VF dynamic pressure ratio	η_{VF}	VNF	N-D	.65 - .80
Tail rotor induced velocity effect at VF	$k_{V_{TR}}$	XKVTR	N-D	1.0
Aircraft mass and inertia				
Aircraft weight	W_{ic}	WAITIC	lb	3944.7
Aircraft roll inertia	I_{XX}	XIXXIC	slug-ft^2	1208.4
Aircraft pitch inertia	I_{YY}	XIYYIC	slug-ft^2	2938.9
Aircraft yaw inertia	I_{ZZ}	XIZZIC	slug-ft^2	2228.0
Aircraft cross product of inertial	I_{YZ}	XIXZIC	slug-ft^2	363.0

TABLE A-11.- CONTINUED

Name	Algebraic symbol	Computer mnemonic	Units	Example value
Center of gravity stationline	$STA_{c.g.}$	STAGG	in.	108.7
Center of gravity waterline	$WL_{c.g.}$	WLCG	in.	39.3
Center of gravity buttline	$BL_{c.g.}$	BLCG	in.	1.4
<u>Fuselage (Fus)</u>				
Fus aerodynamic reference point stationline	STA_{ACF}	STAACF	in.	114.2
Fus aerodynamic reference point waterline	WL_{ACF}	WLACF	in.	58.2
Fus drag, $\alpha = \beta = 0$	D_o/q	D1	ft^2	16.71
Fus drag, variation with α	$\partial(D/q)/\partial\alpha$	D2	ft^2/rad	-1.719
Fus drag, variation with α^2	$\partial^2(D/q)/\partial\alpha^2$	D3	ft^2/rad^2	27.63
Fus drag, variation with β^2	$\partial^2(D/q)/\partial\beta^2$	D4	ft^2/rad^2	71.38
Fus drag, $\alpha = 90°$	$D/q\|\alpha = 90°$	D5	ft^2	50.00
Fus drag, $\beta = 90°$	$D/q\|\beta = 90°$	D6	ft^2	93.00
Fus lift, $\alpha = \beta = 0$	L_o/q	XLO	ft^2	-.5
Fus lift, variation with α	$\partial(L/q)/\partial\alpha$	XL1	ft^2/rad	16.977
Fus side force, variation with β	$M(Y/q)/Mb$	Y1	ft^2/rad	-48.988
Fus rolling moment, variation	$\partial(\ell/q)/\partial\beta$	YL1	ft^3/rad	-28.00
Fus rolling moment, $\beta = 90°$	$\ell/q\|\beta = 90°$	YL2	ft^3	6.0
Fus pitch moment, $\alpha = \beta = 0$	M/q	XM1	ft^3	-58.0
Fus pitch moment, variation with α	$\delta(M/q)/\partial\alpha$	XM2	ft^3/rad	257.8
Fus pitch moment, $\alpha = 90°$	$M/q\|\alpha = 90°$	XM3	ft^3	60.00
Fus yaw moment, variation with β	$\partial(N/q)/\partial\beta$	XN1	ft^3/rad	-343.78
Fus yaw moment, $\beta = 90°$	$N/q\|\beta = 90°$	XN2	ft^3	210.00

TABLE A-11.- CONCLUDED

Name	Algebraic symbol	Computer mnemonic	Units	Example value
Controls				
Swashplate lateral cyclic pitch for zero lateral cyclic stick	$C_{A_{1_s}}$	CAIS	rad	0
Swashplate longitudinal cyclic pitch for zero longitudinal cyclic stick	$C_{B_{1_s}}$	CBIS	rad	0
Longitudinal cyclic control sensitivity	CK_1	CK1	rad/in.	0.036019
Lateral cyclic control sensitivity	CK_2	CK2	rad/in.	0.02452
Main rotor root collective pitch for zero collective stick	C_5	C5	rad	0.01745
Main rotor collective control sensitivity	C_6	C6	rad/in.	0.02618
Tail rotor root collective pitch for zero pedal position	C_7	C7	rad	0.1403
Pedal sensitivity	C_8	C8	rad/in.	0.1073

ENGINE MODEL

The total torque required for the engine degree-of-freedom equations is generated as the summation of reference and first-order terms of a Taylor series expansion about a reference trajectory defined as a function of VEQ (table A-12). The torque supplied for the SCAT will be similar to what the Allison model 250-C30R engine provides. The torque and rpm derivatives (table A-13), supplied by Hughes Helicopters Inc. were needed to include the engine dynamics in the equations of motion. The model assumes there are no drive system dynamics ($N_p = k\Omega$). A hydromechanical unit (HMU) and an electronic control unit (ECU) are represented.

Approach

The torque required equation is expressed as

$$Q_R = Q_{Ref} + \Delta Q_r$$

where

$$\Delta Q_{REQ} = \frac{\delta Q_R}{\delta \omega} \cdot \Delta\omega + \frac{\delta Q_R}{\delta q} \cdot q + \frac{\delta Q_R}{\delta p} \cdot p + \frac{\delta Q_R}{\delta r} \cdot r$$

$$+ \frac{\delta Q_R}{\delta \theta_o} \cdot \Delta\theta_o + \frac{\delta Q_R}{\delta \theta_{TR}} \cdot \Delta\theta_{TR} + \frac{\delta Q_R}{\delta \Omega} \cdot \delta\Omega$$

and QREF are reference (trim) values as a function of VEQ (table A-12).

TABLE A-12.- TORQUE REFERENCE TRIM VALUES

VEQ, knots	0	10	20	40	60	80	100
COLL POSITION (%)	37.5	35.6	32.8	30.0	31.0	35.6	56.3
Ft-lb/TORQR, TORQS	322.0	288.0	245.0	196.8	203.36	265.9	489.96

The torque supplied equation is expressed as:

$$Q_s = Q_s(\text{ref}) + \Delta Q_s$$

where $Q_s(\text{ref})$ is a function of initial collective position (table A-12) and ΔQ_s is a function of the change in collective position fed through an ECU & HMU with an

rpm feedback loop. Values for Q_R as a function of airspeed were taken from engine performance data (figs. A-1 through A-3).

The block diagram in figure A-4 shows the low frequency representation of the engine speed control.

This linear model is good for ±6% N_G changes about 91% N_G.

The resultant changes in rpm (Ω) are included in the aerodynamic coupling equations.

TABLE A-13.- ENGINE TORQUE AND ROTOR SPEED DERIVATIVES

$$\frac{1}{I_{E+R}} \frac{\delta Q_r}{\delta \omega} = 0.00661 \text{ 1/ft-sec (QW)}$$

$$\frac{1}{I_{E+R}} \frac{\delta Q_r}{\delta q} = -0.570 \text{ 1/sec (QQ)}$$

$$\frac{1}{I_{E+R}} \frac{\delta Q_R}{\delta p} = -0.837 \text{ 1/sec (QP)}$$

$$\frac{1}{I_{E+R}} \frac{\delta Q_R}{\delta r} = -0.347 \text{ 1/sec (QR)}$$

$$\frac{1}{I_{E+R}} \frac{\delta Q_R}{\delta \theta_o} = 0.206 \text{ 1/sec}^2\text{/deg (QTHO)}$$

$$\frac{1}{I_{E+R}} \frac{\delta Q_R}{\delta Q_R} = 0.0112 \text{ 1/sec}^2\text{/deg (QTHTR)}$$

$$\frac{1}{m} \frac{\delta Z}{\delta \Omega} = -2.52 \text{ ft/sec (aero derivative) ZOMEGA}$$

$$\frac{1}{I_{E+R}} \frac{\delta Q_R}{\delta \Omega} = 0.543 \text{ 1/sec (QOMEGA)}$$

$$\frac{1}{I_{zz}} \frac{\delta N}{\delta \Omega} = 0.062 \text{ 1/sec (aero derivative) NOMEGA}$$

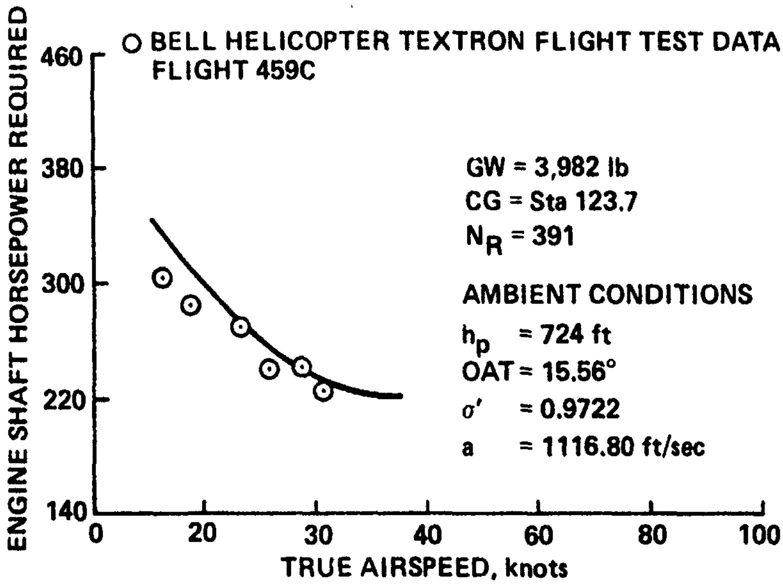


Figure A1.- OH-58 flight test data (10-40 knots).

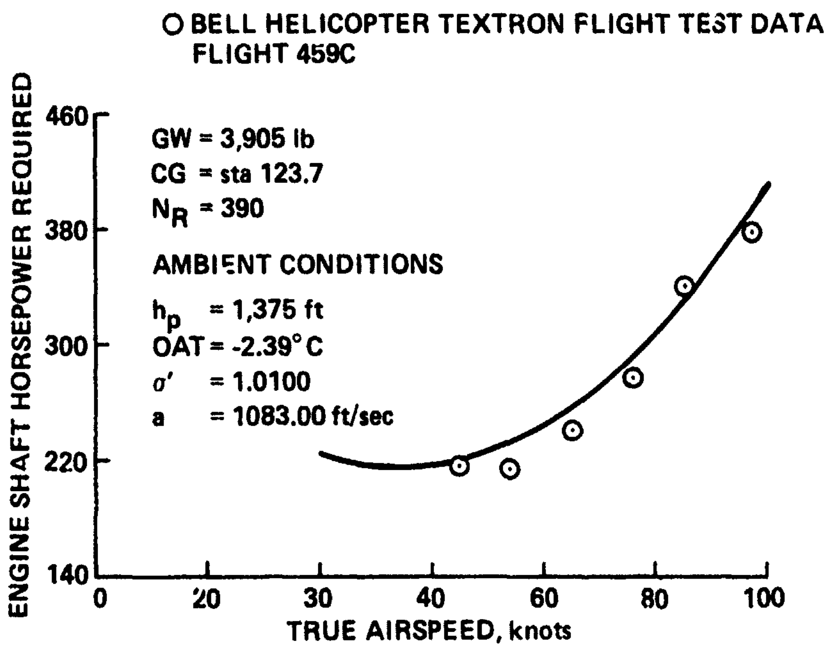


Figure A2.- OH-58 flight test data (60-120 knots).

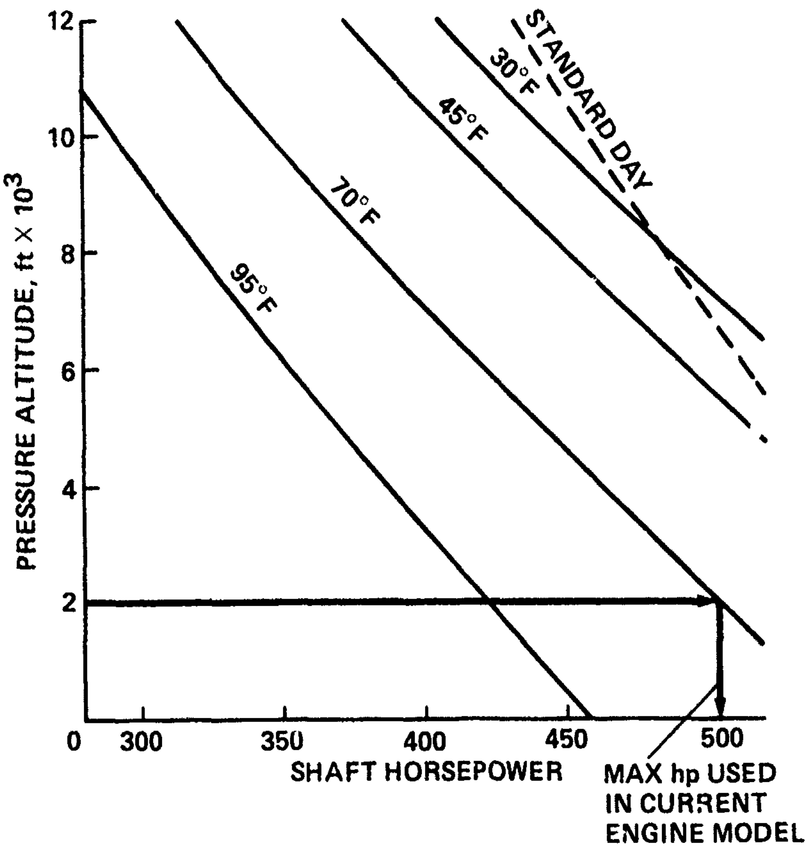


Figure A3.- Installed engine maximum continuous power available.

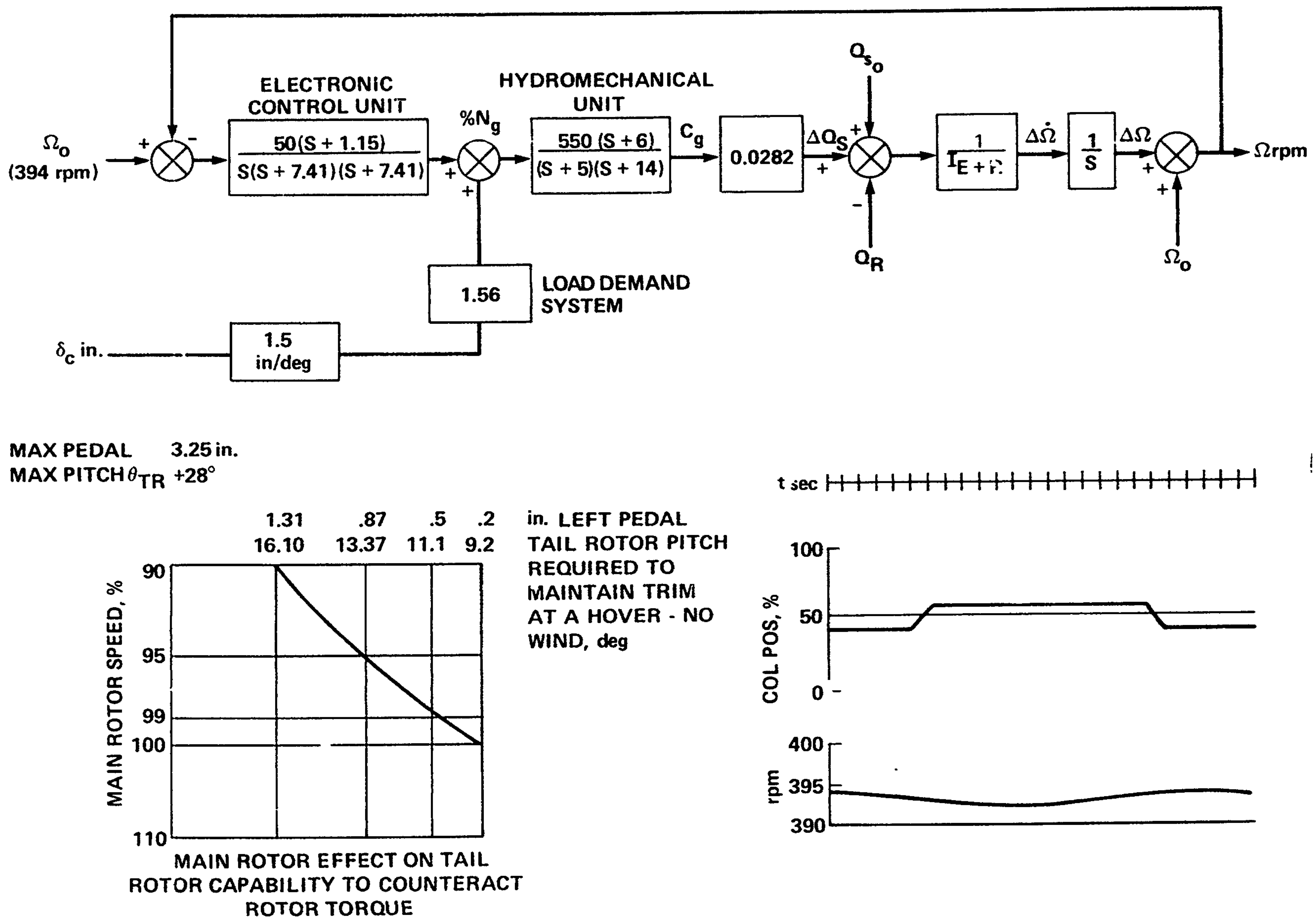


Figure A4.- SCAT engine model.

SUMMARY OF EQUATIONS

Variables

I_{E+R} = combined power turbine/rotor inertia = 607.2 slug-ft^2

N_p = power turbine speed (rad/sec)

Q_R = required aero torque (ft-lb)

Q_s = supplied torque (ft-lb)

C_G = torque to power turbine (ft-lb)

$\% N_G$ = gas generator speed (percent)

Ω = rotor speed (rad/sec)

Engine rpm = 6000

Q_R(TORQ) = TORQR + DELTORQ where TORQR represents the values of VEQ and DELTORQ = QW*PWB + QQ*QB + QP*PB + QR*RB + QTHØ*DTHETϕ + QTHTR*DTHETTR + QOMEGA*DOMEGA

Q_s(TORQS) = TORQSR + DELTORQS where TORQSR represents values of VEQ and DELTORQS is derived from:

$$\Delta Q_s(\text{DELTORQS}) = 0.475 \text{ CG}$$

where

$$C_G = \frac{550(S + 6)}{(S + 5)(S + 14)} \% N_G$$

and %NG = 3.35 DELTHETØ + 50 (S + 1.15). Finally:

$$\text{TTORQ} = \text{TORQS} - \text{TORQ}$$

$$\text{DMOEGA} = \frac{1}{S} + \frac{\text{TTORQ}}{I_{E+R}}$$

and

$$\Omega(\text{OMEGA}) = \text{OMEGAR} + \text{DOMEGA}$$

DISPLAY DYNAMICS

The purpose of the display dynamics portion of the mathematical model is to produce the signals used to drive the moving symbols on the electronic displays. These signals are either simply elements of the aircraft state vector or the result of certain logic applied to selected state vector elements to produce the desired dynamic characteristics. The moving symbols are organized in this section on the basis of the type of information they convey; that is, orientation, situation, command, and fire control.

An additional function of this portion of the program is to alter the display logic as a function of five discrete display modes--cruise, transition, hover, bob-up and fire control--which are selected manually by the pilot.

The operational requirements associated with each display mode are defined as:

1. Cruise--high-speed level flight enroute to the forward line of troops (FLOT).

2. Transition--low-speed nap-of-the-earth maneuvers, such as dash, quick stop, sideward flight, decelerations.

3. Hover--stable hover with minimum drift.

4. Bob-up--unmask and remask maneuvers over a selected horizontal ground position.

5. Fire control--acquiring and tracking aerial/ground target for weapon delivery during any of the above phases.

In addition to the electronic display symbol drive logic, the display dynamics program will also provide signals for the following cockpit instruments:

1. Attitude-director indicator (ADI).
2. Horizontal situation indicator (HSI).
3. Radar altimeter.
4. Barometric altimeter.
5. Instantaneous vertical speed indicator (IVSI).
6. Airspeed indicator.
7. Engine torque.
8. Normal accelerometer.

FLIGHT CONTROL DISPLAY LOGIC

A SCAT basic electronic display format is illustrated in figure A-5. The primary symbols used by the pilot to control the aircraft are the velocity vector, cyclic director symbol, and hover position symbol. The logic and scaling of the parameters that drive these symbols vary as a function of display mode.

Transition mode- The velocity vector is driven directly by the horizontal components of Doppler velocity in the transition mode; that is, displayed vertical motions of the vector are driven by the longitudinal component (X) and the lateral component (Y) of heading referenced velocity (DH), while its lateral motions are driven by YDH.

The displayed vertical motion of the cyclic director symbol with respect to the top of the velocity vector is driven by washed-out pitch attitude with a washout time constant of 50 sec. Laterally, the symbol is driven by roll attitude for roll angles greater than 5.73° and by washed-out roll attitude for smaller values of roll angle. For the latter case, the washout time constant is 10 sec.

Hover mode- For the smaller values of velocity encountered in the hover, the velocity vector is driven by the longitudinal and lateral components of the heading-referenced velocity (XDH, YDH).

The cyclic director symbol is driven by washed-out pitch attitude (10-sec time constant) and washed-out roll attitude (10-sec time constant).

These changes in logic occur instantaneously at the time of the switch from transition to hover mode.

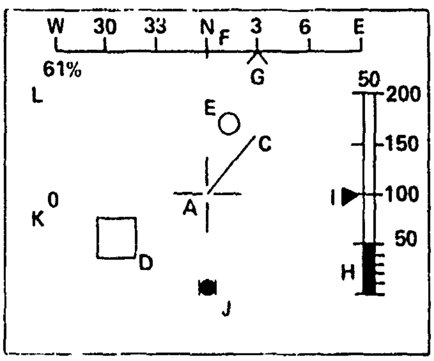
Bob-up mode- The logic driving the velocity vector and cyclic director symbol remains the same as the hover mode logic. The hover position symbol is now driven vertically by EXH and laterally by EYH where EXH and EYH are the integrals of XDH and YDH, respectively, with integration commencing at the time the bob-up display mode is selected. Finally, a command heading symbol, which has remained fixed on the display, is now driven by the difference between the current heading and the heading that existed at the time the bob-up display mode was selected.

Fire control display (aerial target engagement)- This display (fig. A-5) will be used by the pilot when engaging an air target. The following actions will be performed:

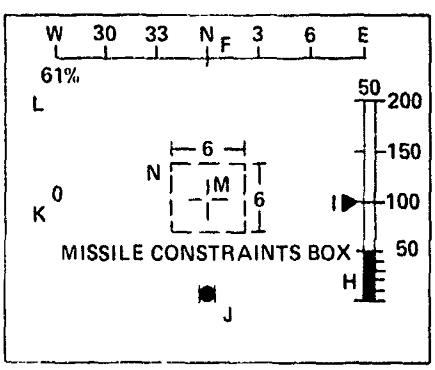
1. Pilot activates the Fire Control HUD symbology using cyclic switch.

2. Pilot maneuvers aircraft to align sight pipper on target ±1°.

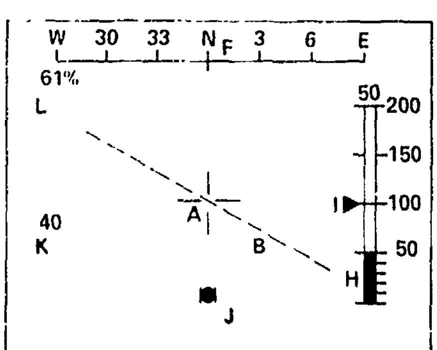
3. Seeker acquisition tone (1.2 KHz) indicates IR energy being received. (Missile launch constraints box appears ±6° EL ±6° AZ).



BOB UP / HOVER MODE



TARGET ACQUISITION MODE



CRUISE / TRANSITION MODE

SYMBOL	INFORMATION
A. AIRCRAFT REFERENCE	FIXED REFERENCE FOR HORIZON LINE VELOCITY VECTOR, HOVER POSITION, CYCLIC DIRECTOR, AND FIRE CONTROL SYMBOLS
B. HORIZON LINE (CRUISE MODE ONLY)	PITCH AND ROLL ATTITUDE WITH RESPECT TO AIRCRAFT REFERENCE (INDICATING NOSE-UP PITCH AND LEFT ROLL)
C. VELOCITY VECTOR	HORIZONTAL DOPPLER VELOCITY COMPONENTS (INDICATING FORWARD AND RIGHT DRIFT VELOCITIES)
D. HOVER POSITION	DESIGNATED HOVER POSITION WITH RESPECT TO AIRCRAFT REFERENCE SYMBOL (INDICATING AIRCRAFT FORWARD AND TO RIGHT OF DESIRED HOVER POSITION)
E. CYCLIC DIRECTOR	CYCLIC STICK COMMAND WITH RESPECT TO HOVER POSITION SYMBOL (INDICATING AIRCRAFT FORWARD AND TO RIGHT OF DESIRED HOVER POSITION)
F. AIRCRAFT HEADING	MOVING TAPE INDICATION OF HEADING (INDICATING NORTH)
G. HEADING ERROR	HEADING AT TIME BOB-UP MODE SELECTED (INDICATING 030)
H. RADAR ALTITUDE	HEIGHT ABOVE GROUND LEVEL IN BOTH ANALOG AND DIGITAL FORM (INDICATING 50 ft)
I. RATE OF CLIMB	MOVING POINTER WITH FULL-SCALE DEFLECTION OF ± 1,000 ft/min (INDICATING 0 ft/min)
J. LATERAL ACCELERATION	INCLINOMETER INDICATION OF SIDE FORCE
K. AIRSPEED	DIGITAL READOUT IN knots
L. TORQUE	ENGINE TORQUE IN percent
M. SIGHT PIPPER	FOV FOR CAGED MISSILE SEEKER (± 1°)
N. CONSTRAINTS BOX	FOV FOR UNCAGED MISSILE SEEKER (± 3°)

Figure A5.- Heads up/panel mounted display symbology.

4. After 2 sec of target being inside missile launch constraints a steady (2.5 KHz) tone will indicate a good track.

5. Pilot depresses fire trigger igniting simulated rocket motor. Launch constraints box flashes at 3 cycles per second.

The derivation of the logic for aerial target fire control sequence proceeds as follows:

Let (X_T, Y_T, Z_T) represent the target position in an aircraft body axis system with the origin at the HUD location. The desired values of target azimuth and elevation are:

$$A_z(\text{PSII}) = \tan^{-1} \frac{Y_T}{X_T}$$

$$E_L(\text{THETI}) = -\sin^{-1} \frac{Z_T}{R_S}$$

where $R_S = \sqrt{x_T^2 + y_T^2 + z_T^2}$. Getting ($X_T$, Y_T, Z_T) is performed by transforming the target position in an Earth-referenced coordinate system to an aircraft body system:

$$\begin{bmatrix} x_T \\ y_T \\ z_T \end{bmatrix} = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \sin\phi\sin\theta\cos\psi - \cos\phi\sin\psi & \sin\phi\sin\theta\sin\psi + \cos\phi\cos\psi & \sin\phi\cos\theta \\ \cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi & \cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi & \cos\phi\cos\theta \end{bmatrix} \begin{bmatrix} x_{TP} \\ y_{TP} \\ z_{TP} \end{bmatrix}$$

Summary of Equations

Orientation- The following parameters are used to derive the moving symbols which provide information on aircraft orientation:

Symbol	Parameter
Aircraft heading	PSI
Horizon line	THET, PHI

Situation- Aircraft position and velocity information in the horizontal and vertical planes are provided to the pilot through the following symbols:

	Symbol	Parameter
Horizontal	Velocity vector	XDH, YDH (TRANSITION) XDHAT, YDHAT (HOVER/BOB-UP)
	Longitudinal, airspeed Lateral	VEQ
	Hover position	EXH, EYH (BOB-UP)
Vertical	Radar altitude	HAGL
	Rate of climb	ALTD

The velocity vector symbol is driven in the transition, hover, and bob-up modes by the true values of ground velocity, XDH, YDH. The ability to vary the scaling of the velocity vector is retained in the display dynamics program. Thus:

VVECX = UKDXD*XDH (TRANSITION) (HOVER/BOB-UP)

and

VVECY = UKDYD*YDH (TRANSITION) (HOVER/BOB-UP)

where UKDXD and UKDYD are constants, the values of which may be selected by the researcher and which, in general, vary as a function of display mode.

In the bob-up mode, the hover position symbol moves in response to the variables EXH and EYH. Thus:

HDVX = UKD*EXH

and

HOVY = UKDY*EYH

where UKDX and UKDY are constants whose values may be selected by the researcher.

Additional status information includes engine torque and lateral acceleration.

Command- The cyclic director symbol provides "command" information in the horizontal plane which, if properly designed, allows the pilot to reach and maintain a stable hover. Thus,

$$\mathrm{VTIPX} = \mathrm{VVECX} + \mathrm{UKDTHT{*}THET{*}}\ \frac{T_1 s}{T_1 s + 1}$$

$$\mathrm{VTIPY} = \mathrm{VVECY} + \mathrm{UKDPHI{*}PHI{*}}\ \frac{T_1 s}{T_2 s + 1}$$

where UKDTHT and UKDPHI are constants, the values of which may be selected by the researcher and which, in general, vary as a function of display mode; the nominal values of T_1 and T_2 are functions of display mode as follows:

	Transition	Hover/bob-up
T_1, sec	50	10
T_2, sec	10 for PHIR $\leq$ 0.1 ∞ for PHIR > 0.1	10

In addition, a command heading symbol is provided; this symbol is driven by the difference between the current heading and the heading that existed at the time the bob-up display mode was selected (EPSIBU).

Finally, logic for a collective stick director is provided. The director logic is implemented as a weighted sum of altitude and altitude rate which drives the original rate of climb symbol; thus,

$$\text{ALTDRC} + \text{UKDALTD}*\text{ALTD} + \text{UKDHAGL}*(\text{HAGLE}-100)$$

For rate of climb information only, UKDHAGL is set to zero.

Additional status information includes engine torque and lateral acceleration. The expression for engine torque was derived in the section titled "engine model" of this appendix. The torque response to collective pitch is lagged by a first-order filter with a 0.1-sec time constant. Thus:

$$\text{TRQ} = \text{TORQS} * \frac{10}{S + 10}$$

Lateral acceleration is driven by the parameter AYP.

Fire Control (Aerial Target Acquisition)

The equations derived for the azimuth, elevation, and fire control logic are implemented as

$$\text{XT} = \text{T11}*\text{XTP} + \text{T12}*\text{YTP} + \text{T13}*\text{ZTP}$$

$$\text{YT} = \text{T21}*\text{XTP} + \text{T22}*\text{YTP} + \text{T23}*\text{ZTP}$$

$$\text{ZT} = \text{T31}*\text{XTP} + \text{T32}*\text{YTP} + \text{T33}*\text{ZTP}$$

$$PSII = R2D*ATAN2(Y_T/XT)$$

$$THETI = -R2D*ASIN(Z_T/SLANTR)$$

where $SLANTR = XT^2 + YT^2 + ZT^2$. When $PSII - PSI = |1°|$ and $THETI - THET = |1°|$.

Seeker acquisition tone (1.5 KHz) indicates IR energy being received. Missile constraints box also appears.

If $PSII - PSI = |3°|$ and $THETI - THET = |3°|$ for 2 sec, then 2.5 KHz tone sounds. The missile can then be fired.

NOTE: R2D = radians to degrees conversion.

DERIVATION OF THE LINEARIZED SIX-DEGREE-OF-FREEDOM REPRESENTATION OF THE SCAT HELICOPTER

The values of the stability derivatives used in the simulation model were obtained from a nonlinear, total force and moment, mathematical model of a single main rotor helicopter (ref. 22). The model has ten degrees of freedom: six rigid-body, three rotor-flapping, and rotor-rotational. The rotor model assumes rigid blades with rotor forces and moments radially integrated and summed about the azimuth. Table A-11 lists the parameters required to describe a helicopter configuration for use in the computer simulation. Listed are the parameter name, algebraic symbol, computer mnemonic, and units for each parameter. The values for each parameter were taken from AHip source data. Figures A-6 through A-23 illustrate the aircraft trim and some selected stability derivative data from hover to 100 knots. These data are also compared with derived C81 data using AHIP parameters. Also, figures A-24 through A-27 represent the resulting dynamic check data for each of the controlled axes.

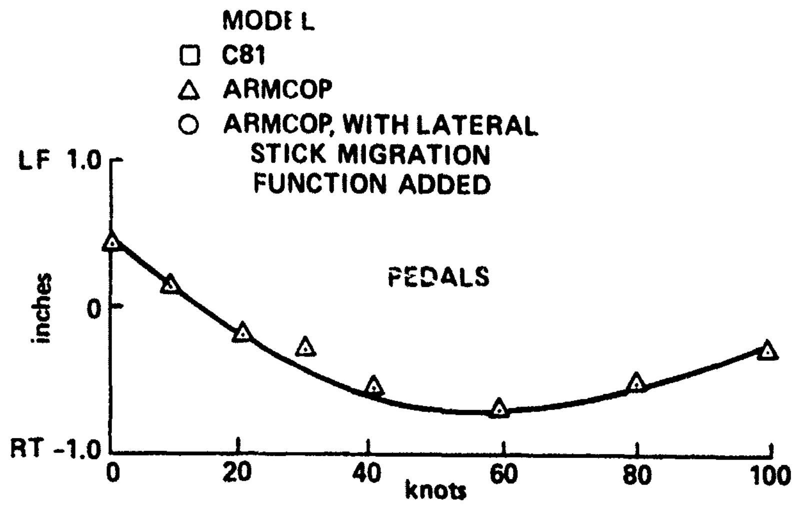


Figure A6.- Tail rotor pedal trim vs airspeed.

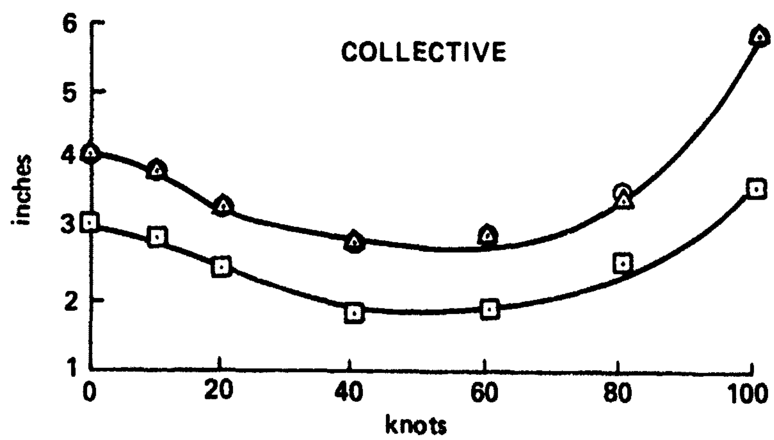


Figure A7.- Collective trim vs airspeed.

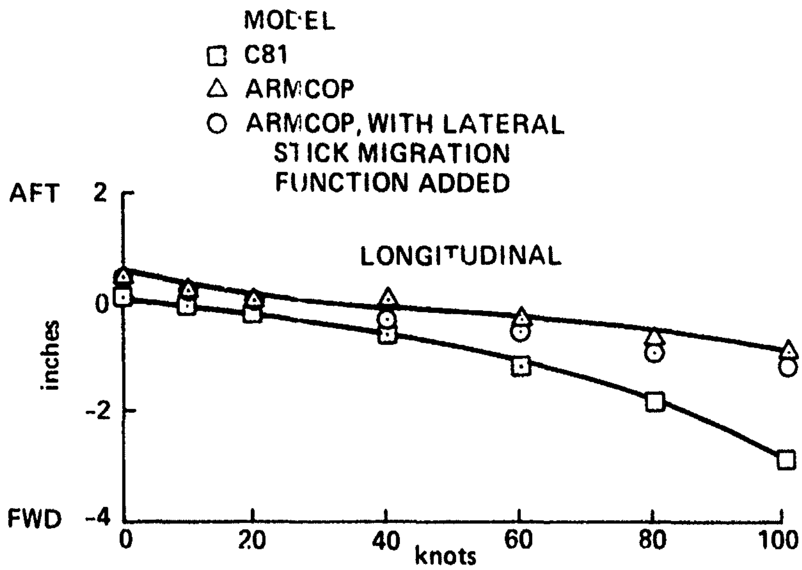


Figure A8.- Longitudinal cyclic trim vs airspeed.

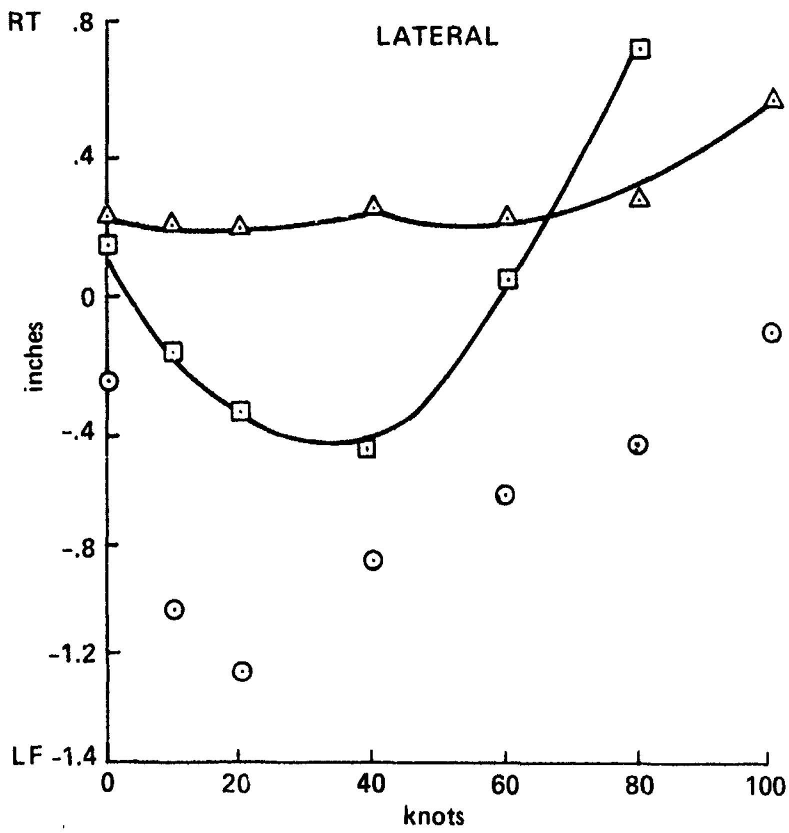


Figure A9.- Lateral cyclic trim vs airspeed.

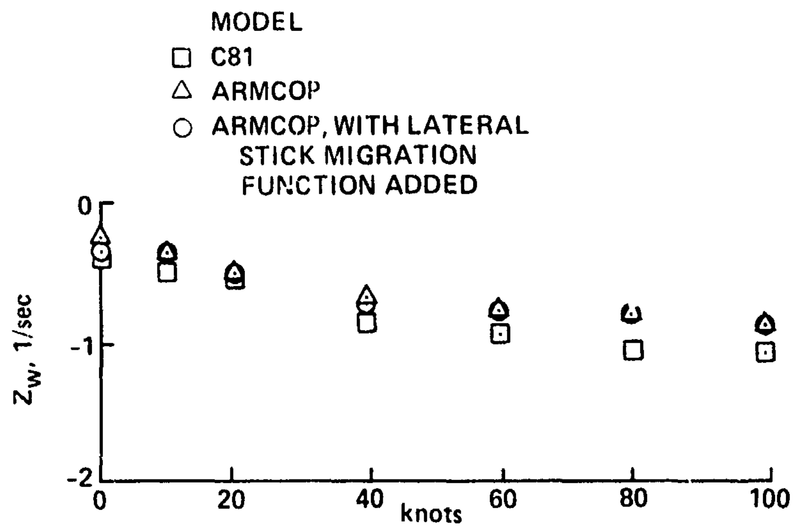


Figure A10.- Vertical damping derivative vs airspeed.

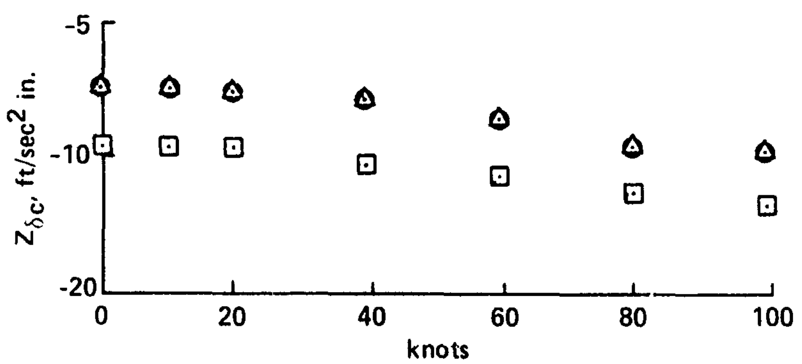


Figure A11.- Z-force due to collective derivative vs airspeed.

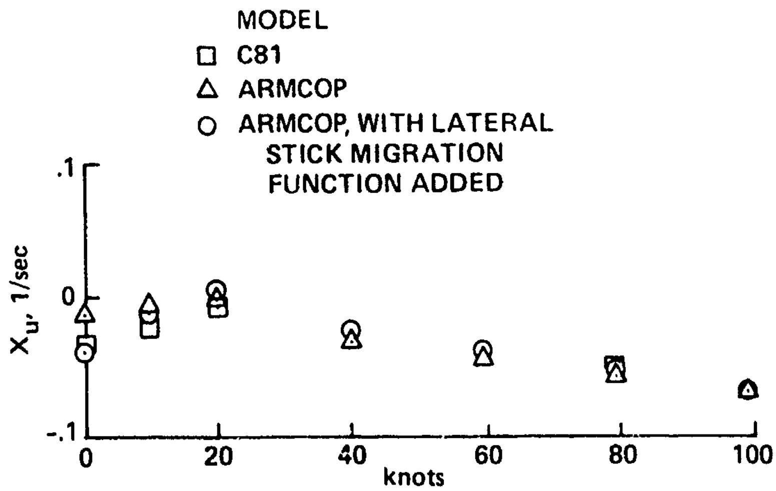


Figure A12.- Drag damping derivative vs airspeed.

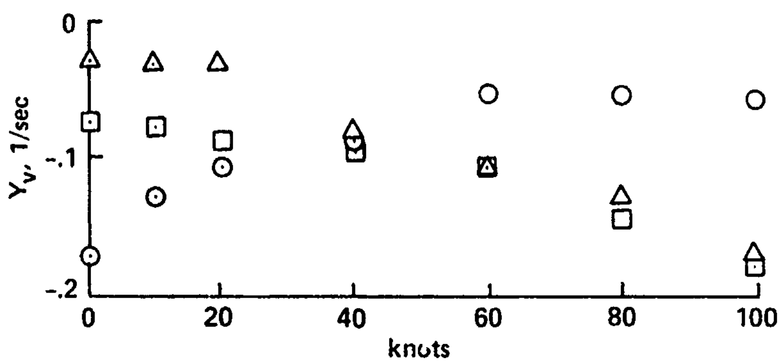


Figure A13.- Side force damping derivative vs airspeed.

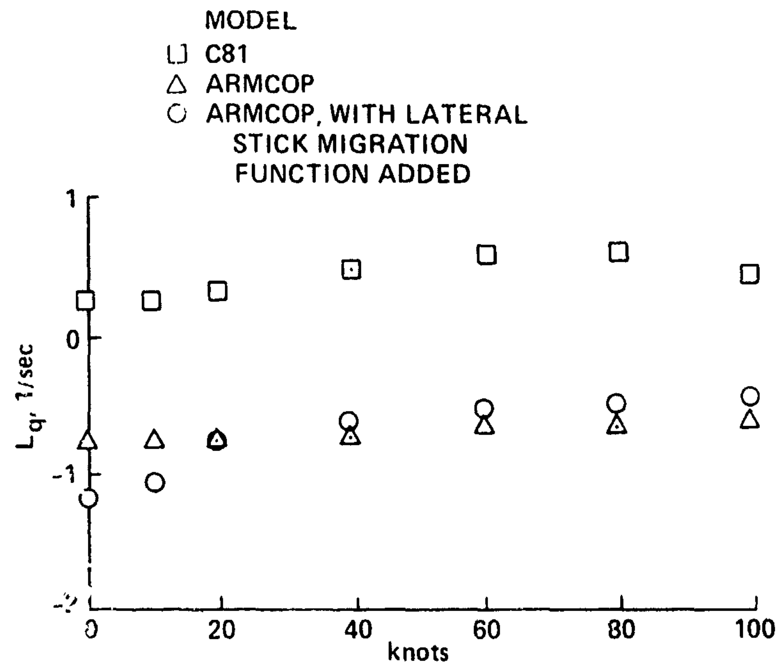


Figure A14.- Roll/pitch coupling derivative vs airspeed.

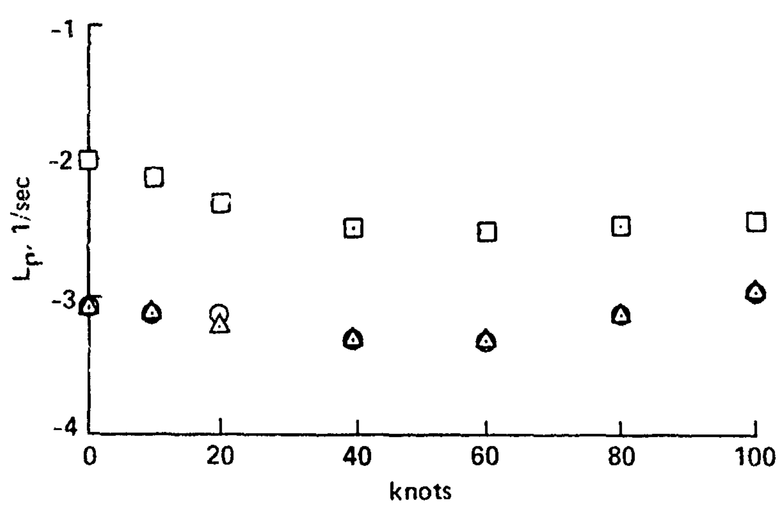


Figure A15.- Roll damping derivative vs airspeed.

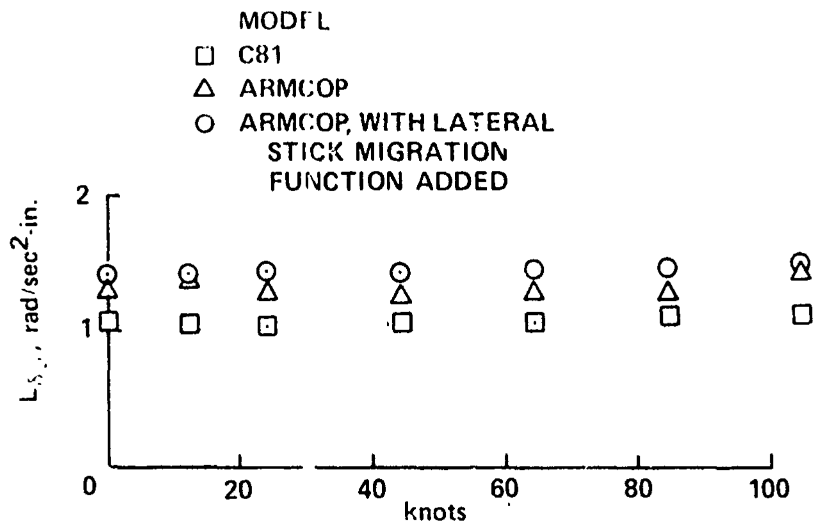


Figure A16.- Roll moment due to lateral cyclic input derivative vs airspeed.

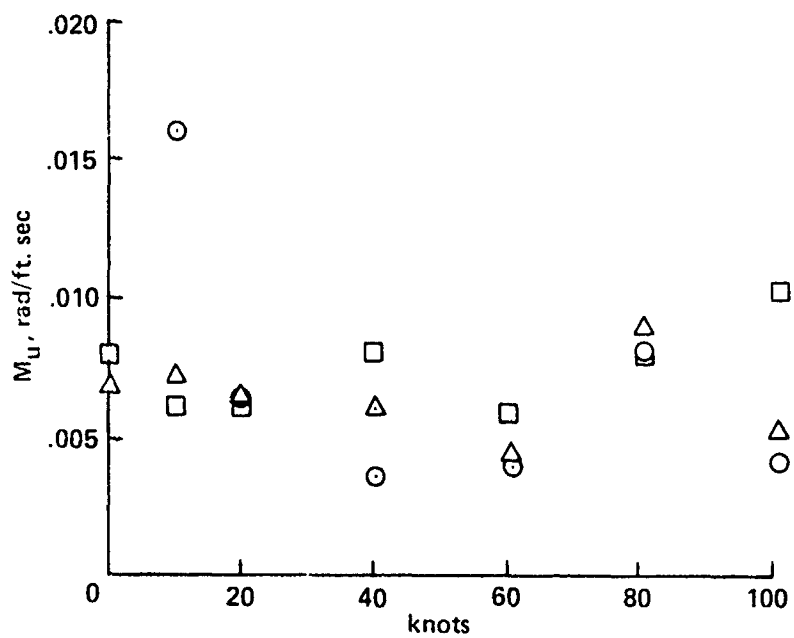


Figure A17.- Roll moment due to forward velocity derivative vs airspeed.

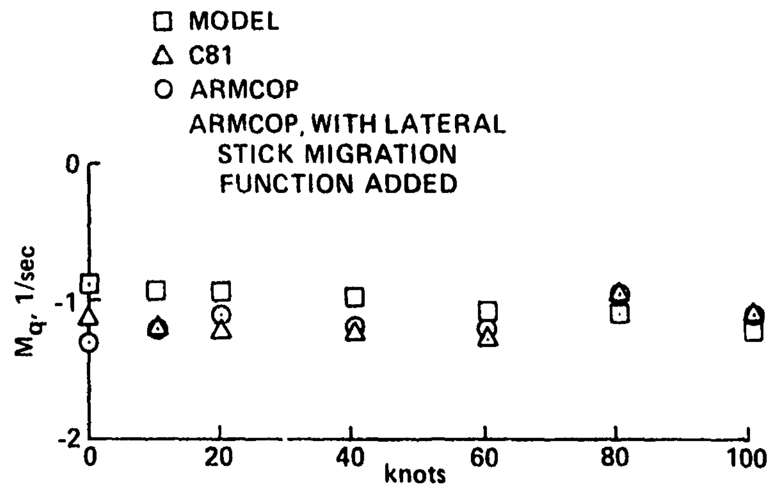


Figure A18.- Pitch damping derivative vs airspeed.

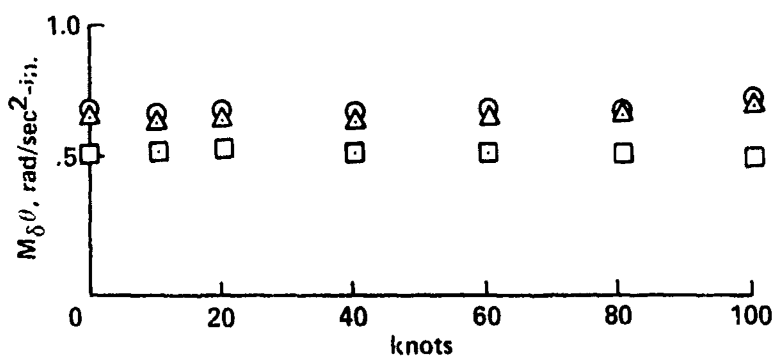


Figure A19.- Pitching moment due to longitudinal cyclic input derivative vs airspeed.

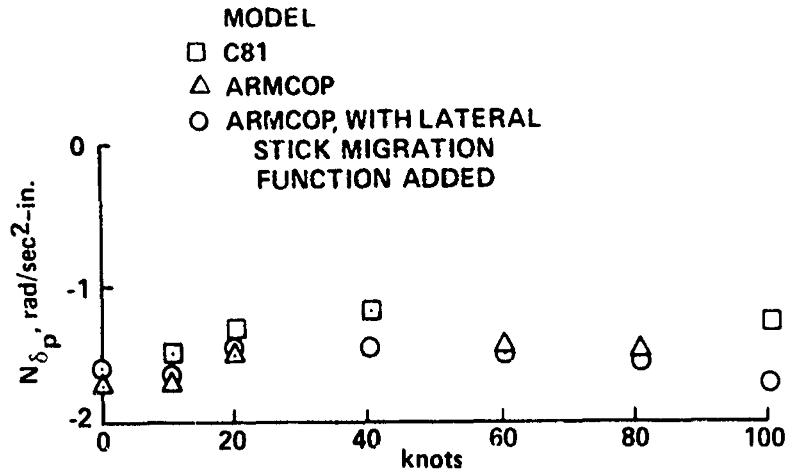


Figure A20.- Yawing moment due to pedal input derivative vs airspeed.

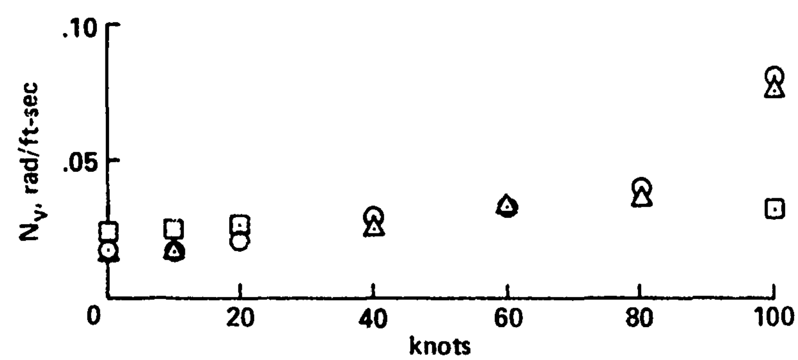


Figure A21.- Yaw weathercock stability derivative vs airspeed.

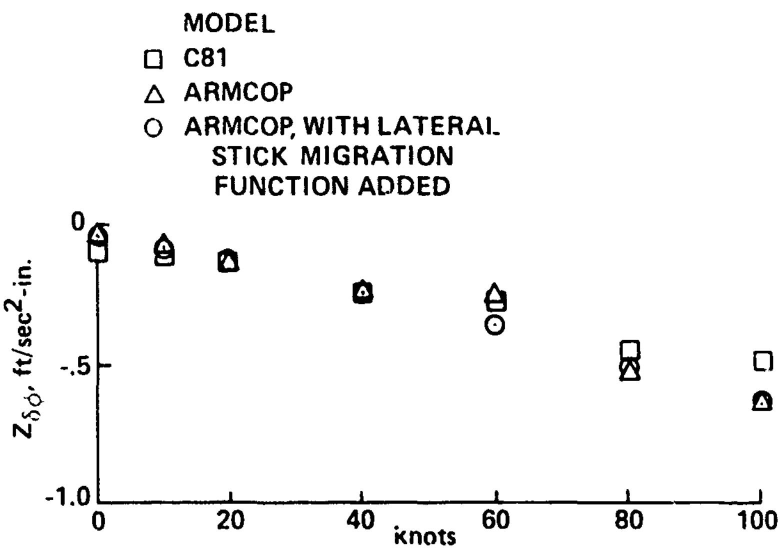


Figure A22.- Z-force due to lateral cyclic input derivative vs airspeed.

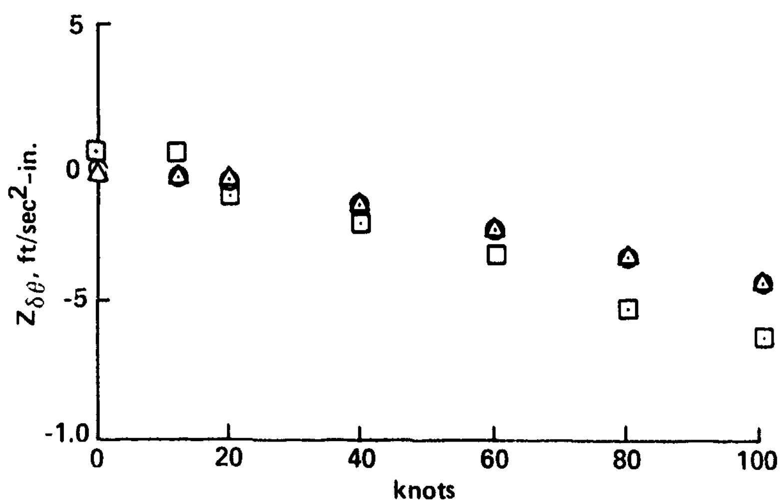


Figure A23.- Z-force due to longitudinal cyclic input derivative vs airspeed.

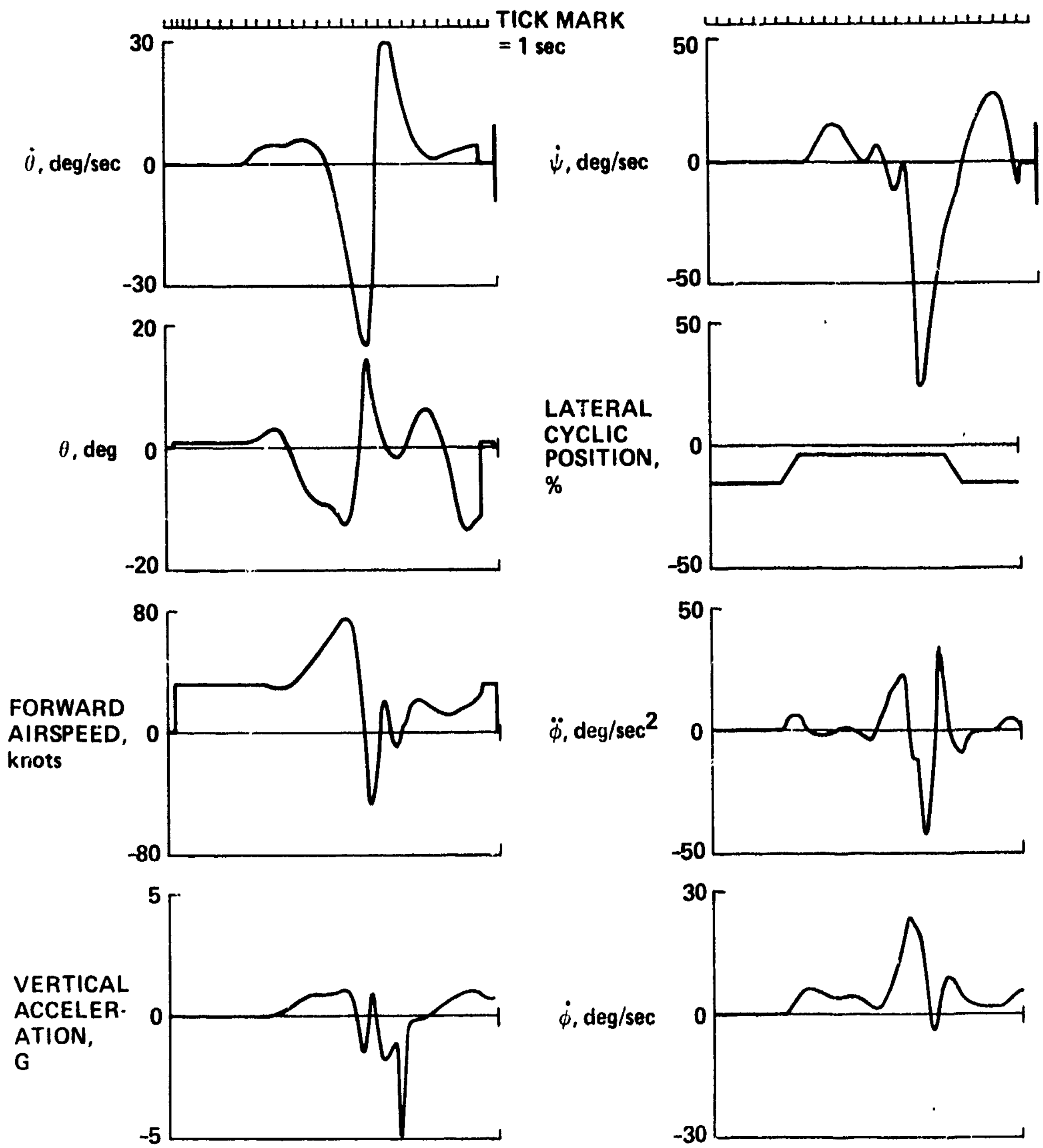


Figure A24.- Time history for 1-in., ramped longitudinal cyclic input (15 sec) - no augmentation.

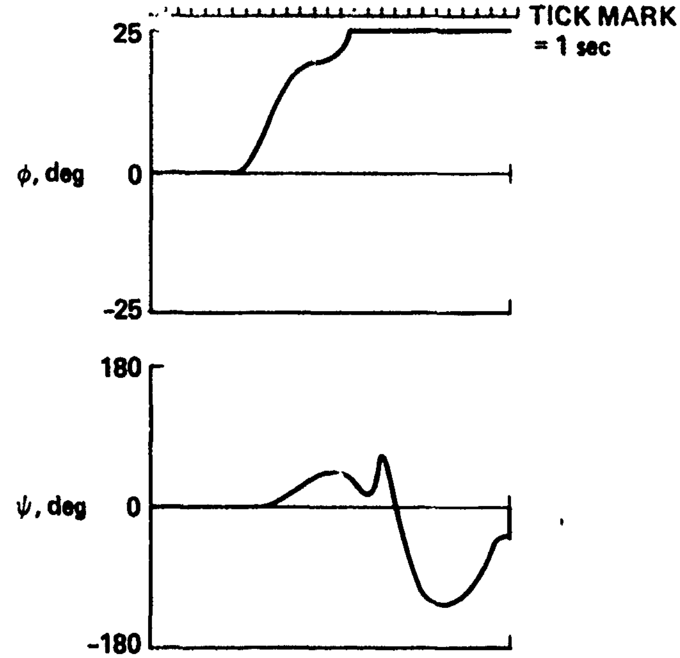


Figure A24.- Concluded.

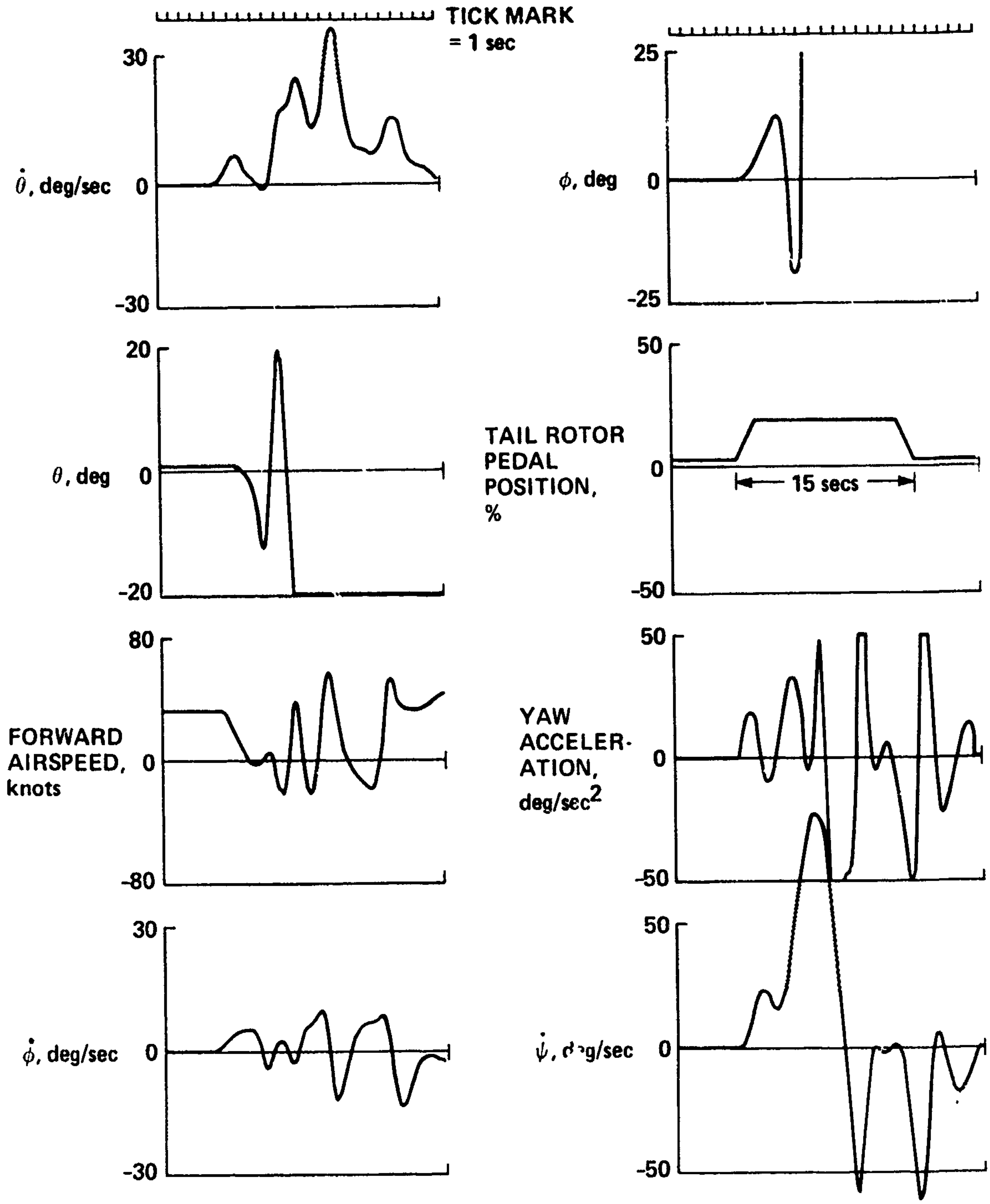


Figure A25.- Time history for 1-in., ramped pedal input (15 sec) - no augmentation.

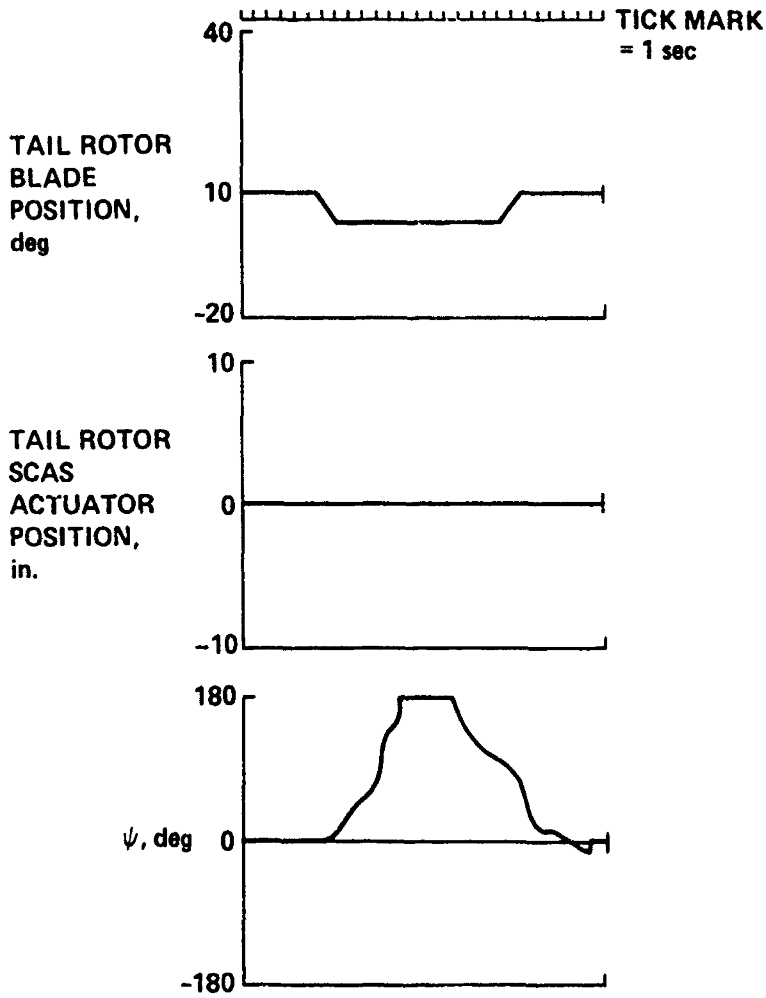


Figure A25.- Concluded.

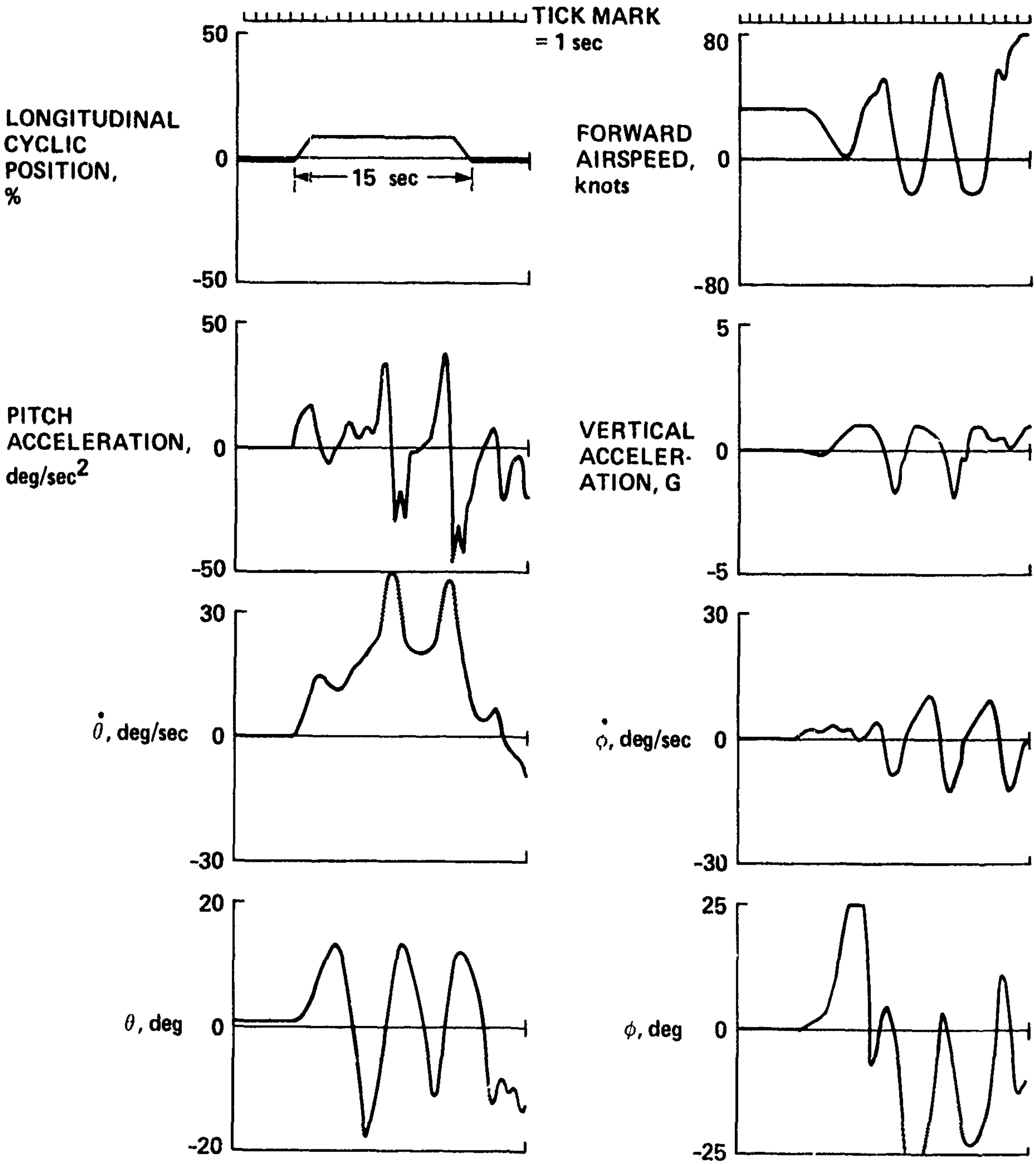


Figure A26.- Time history for 1-in., ramped lateral cyclic input (15 sec) - no augmentation.

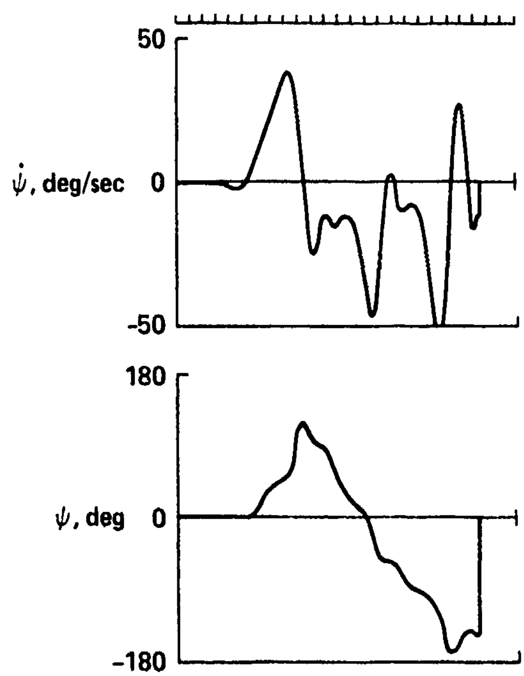


Figure A26.- Concluded.

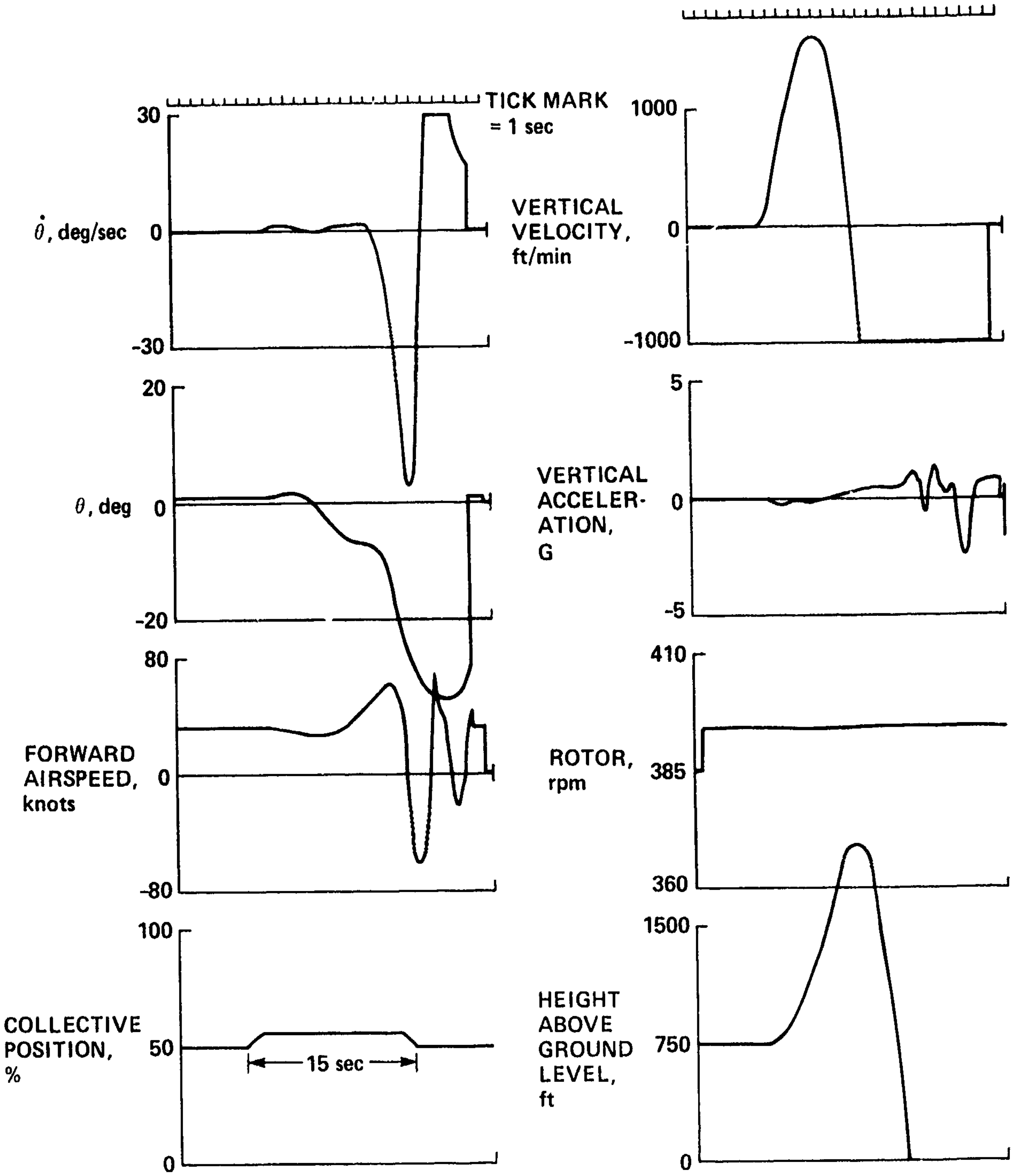


Figure A27.- Time history for 1-in., ramped collective input (15 sec) - no augmentation.

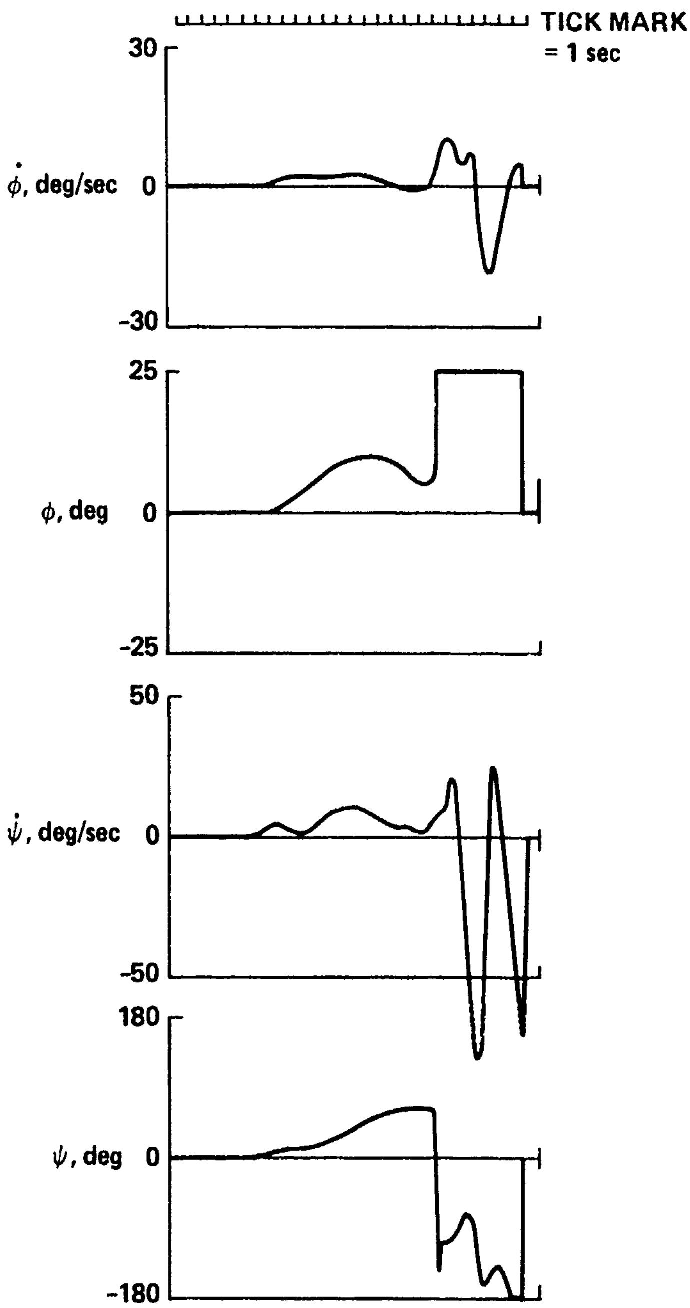


Figure A27.- Concluded.

APPENDIX B

STABILIZATION AND CONTROL SYSTEMS DESCRIPTION

FLIGHT CONTROL SYSTEMS

Four major control system configurations are provided:

1. Mechanical--pitch, roll, yaw
2. SCAS on--pitch, roll, yaw
3. Hover augmentation--pitch, roll, yaw
4. Vertical augmentation--collective

Configuration 1 is based on information from AHIP reference data. Configurations 2 and 3 are derived from reference 14. Configurations 3 and 4 are generic control systems judged to represent useful control system variation for experimental investigations based on Scout/Attack Helicopter Missions. Previous work done in references 13 and 14 was a basis for these systems. In general, a digital representation of the control system transfer functions is obtained by the use of the Z-transform; using computer programs, the appropriate difference equations are obtained from the corresponding S-plane transfer functions. Block diagrams of the various control system configurations are presented in figures B1-B5. The stability derivatives and dynamic check data derived from several of these transfer functions are also listed in this appendix.

MECHANICAL FLIGHT CONTROLS

The baseline mechanical flight control system uses pilot inputs of (1) longitudinal cyclic control (δ_b), (2) lateral cyclic control (δ_a), (3) directional controls (δ_p), and (4) collective control (δ_c) to determine, respectively (1) longitudinal swash-plate angle (B1S), (2) lateral swash-plate angle (A1S), (3) tail rotor collective pitch (θ_{TR}), and (4) main rotor collective pitch (θ_o). The relationships between the pilot control position and control surface position for the basic airframe are as follows:

<u>Longitudinal</u>-

$$B_{1S} = 0.0 - 2.06\,\delta_e \qquad \text{Limits} \quad \begin{array}{l} \delta_e\text{: } \pm 5.33 \text{ in.} \\ B_{1S}\text{: } +11^\circ,\ -11^\circ \end{array}$$

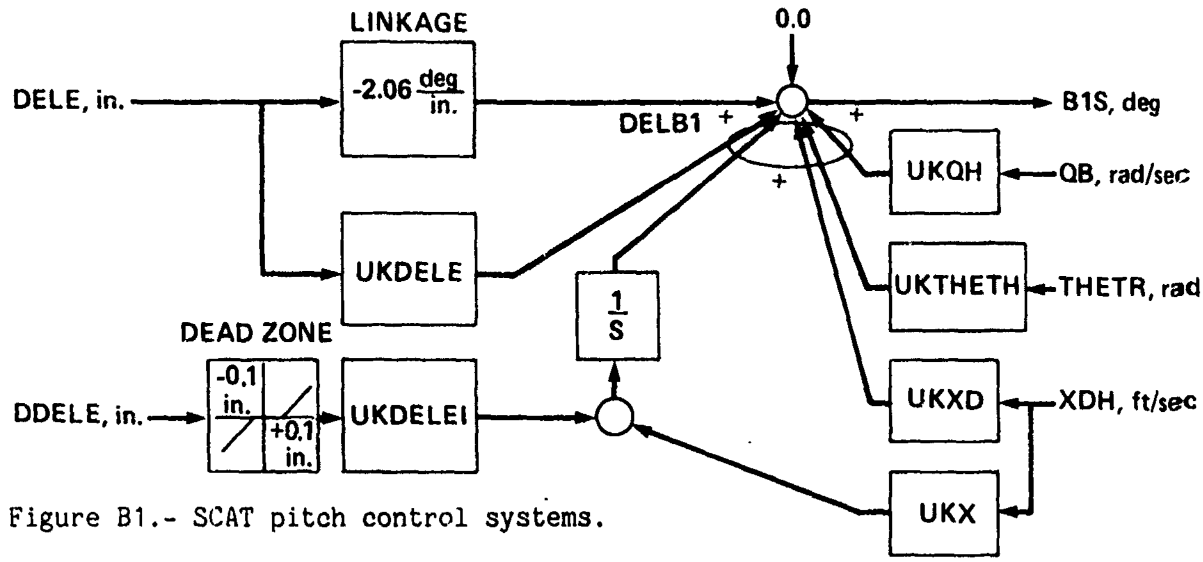


Figure B1.- SCAT pitch control systems.

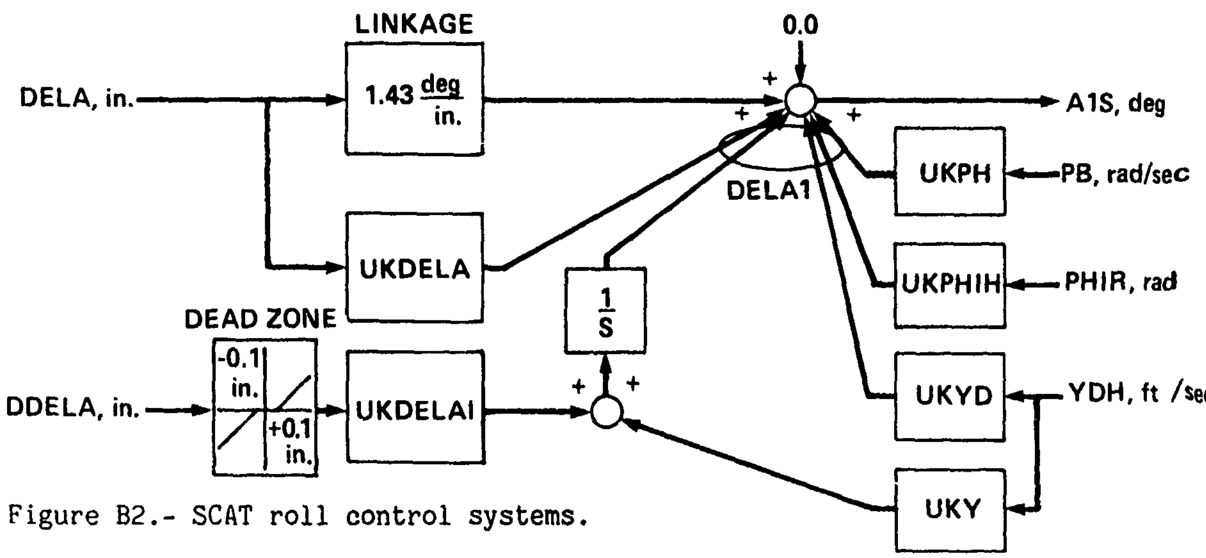


Figure B2.- SCAT roll control systems.

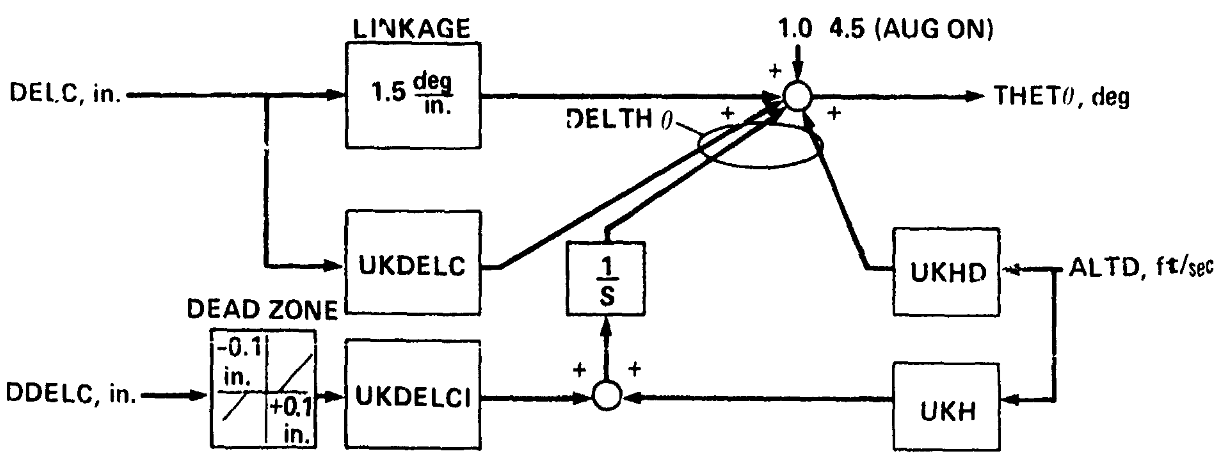


Figure B3.- SCAT vertical control systems.

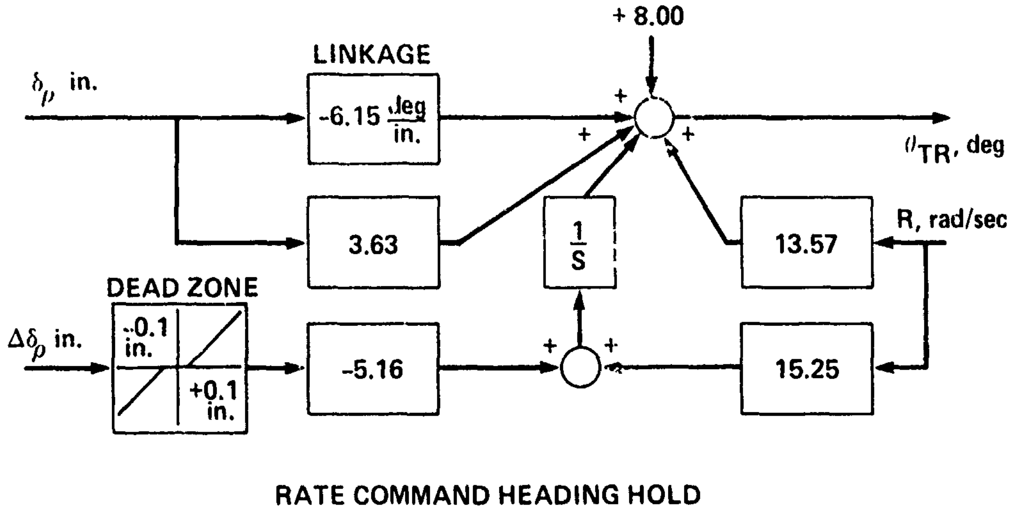


Figure B4.- SCAT rate command heading hold system.

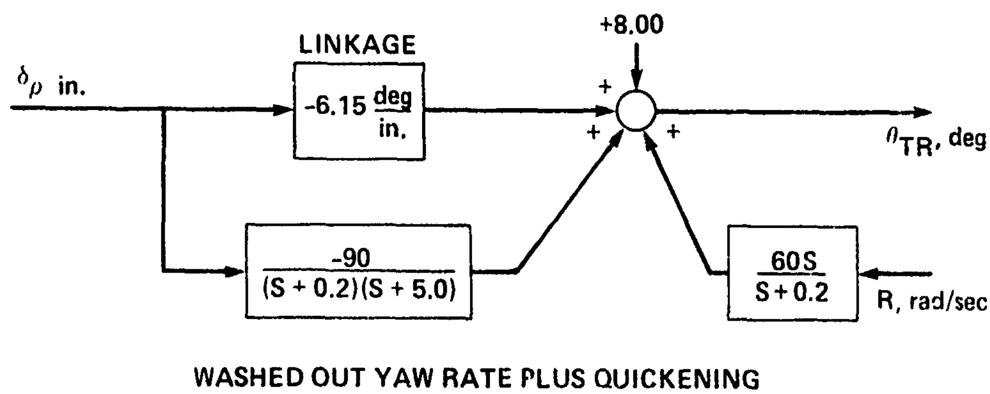


Figure B5.- SCAT yaw axis control system.

Lateral-

$$A_{1S} = 0.0 + 1.43\ \delta_a \qquad \text{Limits} \quad \begin{matrix} \delta_a\text{: } \pm 5.33 \text{ in.} \\ A_{1S}\text{: } +6^\circ,\ -6^\circ \end{matrix}$$

Directional-

$$\theta_{TR} = 8.00 - 6.15\ \delta_p \qquad \text{Limits} \quad \begin{matrix} \delta_r\text{: } \pm 3.25 \text{ in.} \\ \theta_{TR}\text{: } +28^\circ,\ -12^\circ \end{matrix}$$

Collective-

$$\theta_o = 1.0 + 1.5\ \delta_c \qquad \text{Limits} \quad \begin{matrix} \delta_c\text{: } 0 - 10.65 \text{ in.} \\ \theta_o\text{: } 1^\circ - 17^\circ \end{matrix}$$

STABILITY AND CONTROL AUGMENTATION SYSTEM (SCAS)

Limited or unlimited authority SCAS actuators produce additional control surface motion in response to sensed aircraft motion parameters (SAS) and pilot control inputs (CAS) in the longitudinal, lateral, and directional axes. The SCAS control mode may be selected by the researcher for each axis individually or for all three axes collectively. The transfer functions for the SCAS are presented below together with the simplifications employed for the purposes of the simulation.

Longitudinal SCAS-

$$\delta B_1 = \frac{\delta B_1}{\theta} \cdot \theta + \frac{\delta B_1}{u} \cdot u + \frac{\delta B_1}{\delta e} \cdot \delta e$$

where

$$\frac{\delta B_1}{\theta}(s) = \frac{8.54\ s^2(s + 1.756)}{(s + 0.1)(s + 0.145)} + \frac{10.62(s + 0.3)(s + 0.975)}{(s + 0.15)} \sim \text{deg/rad}$$

Simplifying,

$$\frac{\delta B_1}{\theta}(s) \simeq \frac{8.54\ s^2(s + 1.756) + 10.62(s + 0.1)(s + 0.3)(s + 0.975)}{(s + 0.1)(s + 0.15)}$$

$$= \frac{19.16(s^3 + 1.545\ s^2 + 0.2327\ s + 0.01621)}{(s + 0.1)(s + 0.15)}$$

$$= \frac{19.16(s + 1.386)[s^2 + 2(0.72)(0.11)s + (0.11)^2]}{(s + 0.1)(s + 0.15)}$$

$$\frac{\delta B_1}{\theta}(s) \approx 15.71(s + 1.386)$$

and

$$\frac{\delta B_1}{u}(s) = \frac{4.452 \times 10^{-3}(s + 0.3)(s + 0.975)}{(s + 0.15)(s + 1.0)} \sim \text{deg/ft/sec}$$

Simplifying

$$\frac{\delta B_1}{u}(s) \approx 8.681 \times 10^{-3}$$

finally,

$$\frac{\delta B_1}{\delta e}(s) = \frac{-12.32\ s(s + 1.756)}{(s + 0.145)(s + 0.147)(s + 3.45)}$$

<u>Lateral SCAS-</u>

$$\delta A_1 = \frac{\delta A_1}{\phi} \cdot \phi + \frac{\delta A_1}{\delta a} \cdot \delta a$$

where

$$\frac{\delta A_1}{\phi}(s) = \frac{-1.461\ s^2(s + 2.3)}{(s + 0.1)(s + 0.2)} - \frac{1.45\ s(s + 2.28)}{(s + 0.87)} \sim \text{deg/rad}$$

$$= \frac{-2.911\ s(s + 2.3)(s + 0.0175)(s + 0.5686)}{(s + 0.1)(s + 0.2)(s + 0.87)}$$

Simplifying,

$$\frac{\delta A_1}{\phi}(s) \approx -1.90\ \frac{s(s + 2.3)}{(s + 0.2)}$$

Finally,

$$\frac{\delta A_1}{\delta a}(s) = \frac{0.908\ s(s + 2.3)}{(s + 0.2)(s + 0.2)(s + 0.769)} \sim \text{deg/in.}$$

<u>Directional SCAS-</u>

$$\delta_{TR}(s) = \frac{\delta_{TR}}{r} \cdot r + \frac{\delta_{TR}}{\delta_r} \cdot \delta_r + \frac{\delta_{TR}}{\phi} \cdot \phi + \frac{\delta_{TR}}{v} \cdot v$$

where

$$\frac{\delta_{TR}}{r}(s) = 60.00\ \frac{s}{s + 0.2} \sim \text{deg/rad/sec}$$

and

$$\frac{\delta_{TR}}{\delta_r}(s) = \frac{-90.0}{(s + 0.2)(s + 5.0)} \sim \text{deg/in.}$$

For $V \leq 50$ knots, $d_{TR}/\phi = \delta_{TR}/v = 0$. For $V > 50$ knots only,

$$\frac{\delta_{TR}}{\phi}(s) = \frac{-324.3\ Ks^2}{(s + 0.2)(s + 10)} - \frac{614.8\ Ks}{(s + 0.2)(s + 10)} \sim \text{deg/rad}$$

where $K = 0.5 - 0.00333(V - 50)$ ($V \sim$ knots). Simplifying,

$$\frac{\delta_{TR}}{\phi}(s) \approx \frac{-32.43\ Ks(s + 1.896)}{(s + 0.2)}$$

and

$$\frac{\delta_{TR}}{v}(s) = \frac{-831.4}{V(s + 14.7)} \sim \text{deg/ft/sec}$$

$$\frac{\delta_{TR}}{v}(s) \approx \frac{57.3}{V}$$

SCAS limits- SCAS actuator authority limits were taken from reference 2 as percentages of equivalent full controller deflection as follows:

1. ±10% for pitch and roll SCAS

2. ±15% for yaw SCAS

When SCAS actuator authority is limited, the following control surface limits result:

$$\delta B_1 \rightarrow \pm 1.1^\circ$$

$$\delta A_1 \rightarrow \pm 0.6^\circ$$

$$\delta_{TR} \rightarrow \pm 3^\circ$$

According to reference 7, the attitude hold mode is available below $V = 50$ knots by switching out the CAS in the pitch and roll axes, that is

$$\delta B_1 = \frac{\delta B_1}{\theta} \cdot \theta + \frac{\delta B_1}{u} \cdot u$$

and

$$\sigma A_1 = \frac{\delta A_1}{\phi} \cdot \phi$$

and by providing a pseudo-heading-hold feature in yaw, that is

$$\delta_{TR} = 87.04 \frac{s}{s + 0.2} \frac{s + 1.1}{s + 0.2} r \sim \text{deg}$$

Hover Augmentation Systems

Inertial velocity command and position hold- The implementation of a hover position hold system through the pitch and roll SCAS actuators consists of the following logic:

$$\delta B_1 = K_{\delta_e}\delta_e + K_{\int\delta_e}\int\delta_e + K_q q + K_\theta\theta + K_{\dot{x}}\dot{x}_h + K_x\varepsilon_{x_h}$$

and

$$\delta A_1 = K_{\delta_a}\delta_a + K_{\int\delta_a}\int\delta_a + K_p p + K_\phi\phi + k_{\dot{y}}\dot{y}_h + K_y\varepsilon_{y_h}$$

where the h subscript indicates positions and inertial velocities in an aircraft heading-referenced axis system with origin at the nominal center of gravity, and the ε terms indicate position errors from the pilot-designated hover point.

Simulation software calculates the north and east components of the aircraft inertial velocity (VNPH and VEPH, respectively). The transformation from these Earth-referenced velocity components to the heading-referenced components utilizes the sine and cosine of the heading angle (SPSI and CPSI) as follows: (SDPH, YDPH)

VNPH = XDPH*CPSI - YDPH*SPSI

VEPH = XDPH*SPSI + YDPH*CPSI

The heading-referenced position errors EXH and EYH are calculated through an integration of the appropriate velocity components which commences when the pilot designates a hover point (see fig. B-6).

These head-referenced quantities are also used by the display dynamics program to calculate the positions of various symbols on the pilot's electronic display.

Rate Command Heading Hold

With the heading hold mode selected, the directional axis SCAS equation becomes:

$$\delta_{TR} = K_{\delta_r}\delta_r + K_{\int\delta_r}\int\delta_r + K_r r + K_\psi\varepsilon_\psi$$

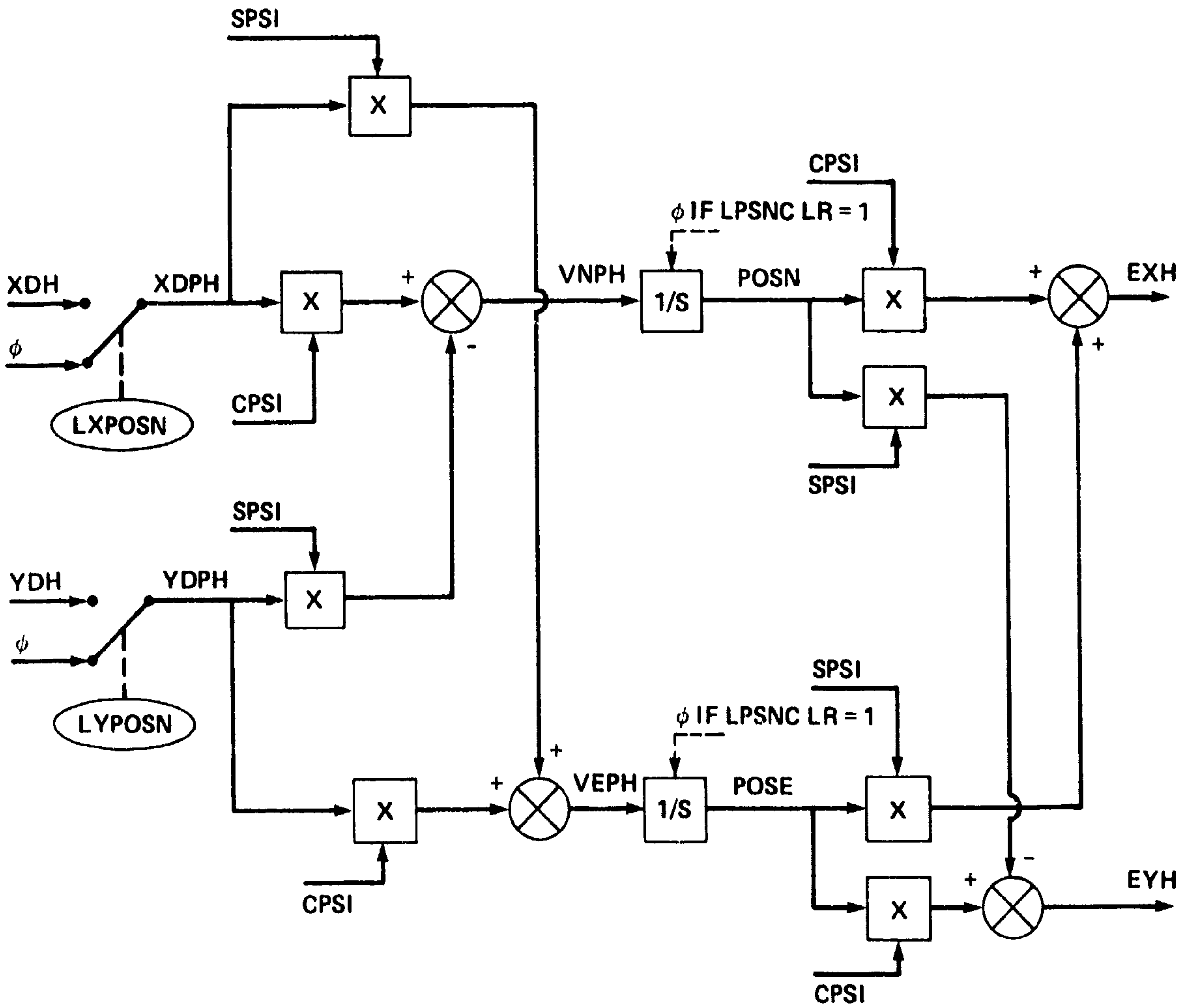


Figure B6.- Heading reference position error derivation.

The intent of this control mode is to provide a yaw rate command-heading hold control system through the pilot's directional controls.

Inertial Velocity Command Altitude Hold

With vertical augmentation selected, a simulated collective SCAS is implemented, consisting of the following logic:

$$\delta_{\theta_o} = K_{\delta_c}\delta_c + K_{\int\delta_c}\int\delta_c + K_{\dot{h}}\dot{h} + K_h\varepsilon_h$$

The objective of this SCAS mode is to provide an altitude rate command-altitude hold control system through the pilot's collective stick.

Summary of Equations

In general, the various control systems to be investigated are implemented as perturbations on the basic mechanical flight control system; that is:

A1S = -0.00 + 1.43*DELA + DELA1

with A1S limited to +6.0° to -6.0°, DELA limited to ±4.27 in., and DELA1 limited to ±0.6°.

B1S = 0.0 - 2.06*DELE + DELB1

with B1S limited to ±11°, DELE limited to ±5.33 in., and DELB1 limited to ±1.1°.

THETTR = +8.00 - 6.15*DELR + DELTR

with THETTR limited to +28° to -12°, DELR limited to ±3.25 in., and DELTR limited to ±3°.

THETØ = 1.0 + 1.5*DELC + DELTHØ

with THETØ limited to 1.0° to 17°, and DELC limited to 0.0 to 10.65 in.

The perturbation quantities DELA1, DELB1, DELTR, and DELTHØ are calculated using logic determined by the control mode selected (tables B-1 through B-4). (The SCAS actuator limits specified above are nominal SCAT values and may be set to any other values by the researcher). Stability derivatives for selected cases are listed in tables B-5 through B-16. Time histories for selected cases are given in figures B-7 through B-11.

Control nonlinearities- Dead zones are included in the integral feed forward paths for all the hover-vertical augmentation systems to prevent drift caused by the integration of inadvertent pilot control inputs. The size of the dead zones, ±0.1 in., was selected to be large enough to prevent any noticeable drift effects even in turbulent conditions yet small enough so as not to affect adversely the system response to control inputs.

TABLE B-1.- δ_{B1} LOGIC

Control mode	DELB1 =
Pitch SCAS on	$\left[\frac{-12.32\ s(s + 1.756)}{(s + 0.145)(s + 0.147)(s + 3.45)}\right]$*DELE + 21.77*THETR + 15.71*QB + 0.008681*UB
Hover augmentation	UKDELE*DELE + (1/S)*(UKDELEI*DDELE + UKX*XDH) + UKTHETH*THETR = UKQH*QB + UKXD*XDH where DDELE is the perturbation of DELE from its value at the time of engagement passed through a dead zone of ±0.1 in.

TABLE B-2.- δ_{A1} LOGIC

Control mode	DELA1 =
Roll SCAS OFF	
Roll SCAS on	$\left[\frac{0.908\ s(s + 2.3)}{(s + 0.2)(s + 0.2)(s + 0.769)}\right]$*DELA - 1.9*$\left(\frac{s + 2.3}{s + 0.2}\right)$*PB
Hover augmentation	UKDELA*DELA + (1/S)*(UKDELAI*DDELA + UKY*YDH) + UKPHIH*PHIR + UKPH*PB + UKYD*YDH where DDELA is the perturbation of DELA from its value at the time of engagement passed through a dead zone of ±0.1 in.

TABLE B-3.- $\delta_{\theta_{TR}}$ LOGIC

Control mode	DELTR =
Yaw SCAS on	$\left[\frac{-90\ s}{(s + 0.2)(s + 5.0)}\right]$*DELR + 60.0*$\left(\frac{s}{s + 0.2}\right)$*RB + KH*$\left[(-21.61 + 0.06391*UB)*\left(\frac{s + 1.896}{s + 0.2}\right)*PB - \frac{57.3}{UB}*VB\right]$ where
Heading augmentation	UKDELR*DELR + (1/S)*(UKDELR1*DDELR + UKPSI*RB) + UKRH+RB where DDELR is the perturbation of DELR from its value at the time of engagement passed through a dead zone of ±0.1 in.

TABLE B-4.- δ_{θ_0} LOGIC

Control mode	DELTHØ =
Collective augmentation	UKDELC*DELC + (1/S)*(UKDELC1*DDELC + UKAH*ALTD) + UKHD*ALTD where DDELC is the perturbation of DELC from its value at the time of engagement passed through a dead zone of ±0.1 in.

NOTES: (1) The previous derivatives used other than unity for step sizes in the independent variable. Therefore, all of the derivatives had to be divided through by the step size.

(2) Also, in running the stability derivative program, the transfer functions for the augmentation were put in front of the basic A/C control linkage; therefore, to get the correct control derivatives, the previous control derivatives must be divided through by the respective control linkage conversion factors: Pitch--1.90 and Roll--1.3 (includes mechanical feed forward loop), TR--6.15, and COLL--3.09 (includes mechanical feed forward loop.

TABLE B-5.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW SCAS (HOVER CASE)

USER IDENTIFICATION : SCAT

TRIMMED AIRSPEED = 1.Ø KNOTS
RELATIVE VELOCITY = 1.7 FT/SEC
ANGLE OF ATTACK = 5.21 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = .Ø LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

YAW - SCAS
PITCH, ROLL - IVC
COLLECTIVE -- AUG

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	-.15411E-Ø1	-.1535ØE Ø1	.2Ø418E-Ø1	-.42312E Ø1	.12394E ØØ	-.13Ø5ØE ØØ
/QBIC	.58844E Ø1	.12Ø59E Ø1	.75Ø11E ØØ	-.3739ØE Ø1	-.43268E Ø1	-.3Ø788E ØØ
/RBIC	-.64341E-Ø1	.14615E Ø2	.22327E ØØ	.38998E Ø1	-.17574E ØØ	-.16644E Ø2
/VBIC	.32268E-Ø2	-.47946E-Ø1	.73694E-Ø1	-.5Ø317E-Ø1	-.49552E-Ø2	.12563E-Ø1
/WBIC	.1277ØE ØØ	.32466E-Ø1	-.2ØØ66E Ø1	-.1334ØE-Ø1	-.15291E-Ø1	.1Ø689E ØØ
/DAP	-.31289E ØØ	.1Ø65ØE Ø1	-.4Ø884E-Ø1	.19744E Ø1	.23ØØ4E ØØ	.63899E-Ø1
/DEP	-.967Ø4E ØØ	-.28499E ØØ	[illegible]	[illegible]	[illegible]	[illegible]
/DRP	.25573E-Ø2	-.14674E Ø1	-.14546E-Ø2	-.4114ØE ØØ	.17525E-Ø1	.16578E Ø1
/DCP	.52732E ØØ	.16655E ØØ	-.78672E Ø1	-.1Ø624E ØØ	-.66565E-Ø1	.51453E ØØ
/UBIC	-.55853E-Ø1	.26Ø77E-Ø1	.44661E-Ø1	.1Ø95ØE ØØ	.4Ø855E-Ø1	-.99113E-Ø2

TABLE B-6.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW SCAS (10 KNOT CASE)

USER IDENTIFICATION : SCAT

TRIMMED AIRSPEED = 1Ø.Ø KNOTS
RELATIVE VELOCITY = 16.9 FT/SEC
ANGLE OF ATTACK = 5.48 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = .3 LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

YAW – SCAS
PITCH, ROLL – IVC
COLLECTIVE – AUG

		STEP SIZE	UNITS	SCALE FACTOR
INDEPENDENT VARIABLES	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

		UNITS	SCALE FACTOR
DEPENDENT VARIABLES	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	-.84141E-Ø2	-.1715ØE Ø1	.23397E ØØ	-.43176E Ø1	.12215E ØØ	-.16289E ØØ
/QBIC	.58349E Ø1	.13814E Ø1	.2621ØE Ø1	-.37318E Ø1	-.43447E Ø1	-.33Ø27E ØØ
/RBIC	-.11965E ØØ	.1Ø353E Ø2	.26132E ØØ	.27133E Ø1	-.66843E-Ø1	-.11946E Ø2
/VBIC	.41Ø71E-Ø2	-.469Ø3E-Ø1	.6Ø946E-Ø1	-.51Ø36E-Ø1	-.51665E-Ø2	.14399E-Ø1
/WBIC	.12442E ØØ	.26Ø24E-Ø1	-.2Ø244E Ø1	-.16Ø92E-Ø1	-.12794E-Ø1	.97367E-Ø1
/DAP	-.31ØØ9E ØØ	.1Ø66ØE Ø1	-.1Ø222E ØØ	.21ØØ6E Ø1	.23ØØ4E ØØ	.69ØØ9E-Ø1
/DEP	-.95ØØØE ØØ	-.28499E ØØ	-.37781E ØØ	.59847E ØØ	.62697E ØØ	.22787E-Ø1
/DRP	.21426E-Ø1	-.25176E Ø1	-.12843E-Ø1	-.7Ø7Ø8E ØØ	.16Ø72E-Ø1	.2859ØE Ø1
/DCP	.4928ØE ØØ	.16798E ØØ	-.768Ø1E Ø1	-.112ØØE ØØ	-.46411E-Ø1	.47998E ØØ
/UBIC	-.487Ø3E-Ø1	.27763E-Ø1	.3Ø544E-Ø1	.1Ø231E ØØ	.382Ø4E-Ø1	-.13745E-Ø1

TABLE B-7.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW SCAS
(20 KNOT CASE)

USER IDENTIFICATION : SCAT

YAW – SCAS
PITCH, ROLL – IVC
COLLECTIVE – AUG

TRIMMED AIRSPEED = 2Ø.Ø KNOTS
RELATIVE VELOCITY = 33.8 FT/SEC
ANGLE OF ATTACK = 5.82 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS WING AREA = .Ø FT2
SPAN = 4.3 FT CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3 QBAR = 1.4 LB/FT2
IXX = 1Ø28. SLUG-FT2 IZZ = 2228. SLUG-FT2
IYY = 2939. IXZ = 363.

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.19572E-Ø1	-.18427E Ø1	.33323E ØØ	-.43415E Ø1	.11315E ØØ	-.18Ø9ØE ØØ
/QBIC	.57641E Ø1	.1432ØE Ø1	.41881E Ø1	-.37118E Ø1	-.43664E Ø1	-.38293E ØØ
/RBIC	-.13ØØ1E ØØ	.1389ØE Ø2	.33291E ØØ	.37339E Ø1	-.23436E-Ø1	-.16543E Ø2
/VBIC	.51275E-Ø2	-.46388E-Ø1	.58252E-Ø1	-.47949E-Ø1	-.53947E-Ø2	.1804ØE-Ø1
/WBIC	.12196E ØØ	-.61917E-Ø2	-.21228E Ø1	-.22971E-Ø1	-.96331E-Ø2	.78551E-Ø1
/DAP	[illegible]	.1Ø437E Ø1	[illegible]	[illegible]	[illegible]	[illegible]
/DEP	-.91196E ØØ	-.29448E [illegible]	-.66471E [illegible]	.69848E ØØ	.62132E ØØ	.28499E-Ø1
/DRP	.92256E-Ø2	-.13899E Ø1	-.12293E-Ø1	-.39359E ØØ	.24633E-Ø2	.16337E Ø1
/DCP	.45598E ØØ	.25598E-Ø1	-.7632ØE Ø1	-.12159E ØØ	-.2Ø8Ø1E-Ø1	.41599E ØØ
/UBIC	-.75735E-Ø1	-.9Ø339E-Ø2	.1Ø937E ØØ	.4515ØE-Ø1	.36378E-Ø1	-.15819E-Ø1

TABLE B-8.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW SCAS (30 KNOT CASE)

USER IDENTIFICATION : SCAT

YAW – SCAS
PITCH, ROLL – IVC
COLLECTIVE – AUG

TRIMMED AIRSPEED = 3Ø.Ø KNOTS
RELATIVE VELOCITY = 5Ø.7 FT/SEC
ANGLE OF ATTACK = 4.59 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS WING AREA = .Ø FT2
SPAN = 4.3 FT CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3 QBAR = 3.Ø LB/FT2
IXX = 1Ø28. SLUG-FT2 IZZ = 2228. SLUG-FT2
IYY = 2939. IXZ = 363.

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.33Ø62E-Ø1	-.19477E Ø1	.53494E ØØ	-.43866E Ø1	.1Ø615E ØØ	-.19225E ØØ
/QBIC	.57837E Ø1	.15382E Ø1	.57261E Ø1	-.373Ø7E Ø1	-.43371E Ø1	-.4559ØE ØØ
/RBIC	-.24794E ØØ	.1377ØE Ø2	.41147E ØØ	.366Ø3E Ø1	.31448E-Ø1	-.1686ØE Ø2
/VBIC	.68978E-Ø2	-.69671E-Ø1	.51715E-Ø1	-.51ØØ9E-Ø1	-.5713ØE-Ø2	.21513E-Ø1
/WBIC	.11964E ØØ	-.16226E-Ø1	-.2289ØE Ø1	-.28421E-Ø1	-.1359[illegible]-Ø2	.62148E-Ø1
/DAP	-.31Ø97E ØØ	.1Ø437E Ø1	-.26Ø39E ØØ	.19ØØØE Ø1	.23ØØ4E ØØ	.Ø3249E-Ø1
/DEP	-.89295E ØØ	-.3Ø398E ØØ	-.1ØØ96E Ø1	.6Ø323E ØØ	.61845E ØØ	.4Ø849E-Ø1
/DRP	.19982E-Ø1	-.13622E Ø1	-.18446E-Ø1	-.38128E ØØ	-.27625E-Ø2	.16483E Ø1
/DCP	.43Ø37E ØØ	-.56Ø3ØE-Ø2	-.8Ø476E Ø1	-.1328ØE ØØ	-.64Ø87E-Ø2	.36638E ØØ
/UBIC	-.1Ø384E ØØ	-.3834ØE-Ø1	.88328E-Ø1	.16Ø34E-Ø1	.37969E-Ø1	-.13Ø42E-Ø1

TABLE B-9.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW SCAS
(40 KNOT CASE)

USER IDENTIFICATION : SCAT

YAW – SCAS
PITCH, ROLL – IVC
COLLECTIVE – AUG

TRIMMED AIRSPEED = 4Ø.Ø KNOTS
RELATIVE VELOCITY = 67.6 FT/SEC
ANGLE OF ATTACK = 3.37 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = 5.4 LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.46565E-Ø1	-.2Ø526E Ø1	.73653E ØØ	-.44315E Ø1	.99157E-Ø1	-.2Ø358E ØØ
/QBIC	.58Ø36E Ø1	.16443E Ø1	.72627E Ø1	-.37495E Ø1	-.43Ø78E Ø1	-.52883E ØØ
/RBIC	-.36595E ØØ	.1365ØE Ø2	.48992E ØØ	.35868E Ø1	.86332E-Ø1	-.19363E Ø2
/VBIC	.85559E-Ø2	-.93Ø3ØE-Ø1	.45583E-Ø1	-.54Ø91E-Ø1	-.6ØØ38E-Ø2	.24768E-Ø1
/WBIC	.12156E ØØ	-.23Ø52E-Ø1	-.24528E Ø1	-.3Ø972E-Ø1	.65342E-Ø2	.45975E-Ø1
/DAP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
/DEP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
/DRP	.3Ø745E-Ø1	-.13345E Ø1	-.24592E-Ø1	-.36898E ØØ	-.79882E-Ø2	.19Ø64E Ø1
/DCP	.4Ø478E ØØ	-.36792E-Ø1	-.84637E Ø1	-.14399E ØØ	.79834E-Ø2	.3168ØE ØØ
/UBIC	-.74Ø31E-Ø1	-.32Ø72E-Ø1	.734Ø2E-Ø1	.17474E-Ø1	.34236E-Ø1	-.77975E-Ø2

TABLE B-10.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW SCAS
(50 KNOT CASE)

USER IDENTIFICATION : SCAT

```
TRIMMED AIRSPEED =  5Ø.Ø KNOTS                                    YAW - SCAS
RELATIVE VELOCITY =   84.4 FT/SEC                                 PITCH, ROLL -- IVC
ANGLE OF ATTACK =  3.55 DEG                                       COLLECTIVE -- AUG
FLIGHT PATH ANGLE =    .ØØ DEG
WEIGHT =    394Ø. LBS
MASS =  122.4 SLUGS              WING AREA =      .Ø FT2
SPAN =   4.3 FT                  CHORD = 27.7 FT
RHO =   .23736E-Ø2 SLUG/FT3     QBAR =      8.5 LB/FT2
IXX =   1Ø28. SLUG-FT2       IZZ =    2228. SLUG-FT2
IYY =   2939.                IXZ =     363.
```

		STEP SIZE	UNITS	SCALE FACTOR
INDEPENDENT VARIABLES	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ1	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

		UNITS	SCALE FACTOR
DEPENDENT VARIABLES	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.32776E-Ø1	-.2Ø613E Ø1	.87937E ØØ	-.44315E Ø1	.94423E-Ø1	-.22414E ØØ
/QBIC	.56655E Ø1	.16324E Ø1	.9Ø28ØE Ø1	-.37245E Ø1	-.43366E Ø1	-.23Ø28E Ø1
/RBIC	-.41397E ØØ	.13462E Ø2	.4Ø744E ØØ	.34Ø72E Ø1	.191Ø3E ØØ	-.189Ø7E Ø2
/VBIC	.77987E-Ø2	-.1Ø651E ØØ	.41788E-Ø1	-.54164E-Ø1	-.6Ø827E-Ø2	.27ØØ4E-Ø1
/WBIC	.12466E ØØ	-.32721E-Ø1	-.257Ø8E Ø1	-.31Ø43E-Ø1	.14Ø24E-Ø1	.46Ø24E-Ø1
/DAP	-.3Ø3Ø3E ØØ	[illegible] Ø1	-.32864E ØØ	.1Ø59ØE Ø1	.23816E ØØ	[illegible]-Ø1
/DEP	-.Ø4845E ØØ	-.31349E ØØ	-.17411E Ø1	.5Ø799E ØØ	.51Ø9ØE ØØ	.2Ø71ØE ØØ
/DRP	.36897E-Ø1	-.13ØØ7E Ø1	-.14141E-Ø1	-.35359E ØØ	-.18751E-Ø1	.1845ØE Ø1
/DCP	.4Ø796E ØØ	-.6Ø791E-Ø1	-.8815ØE Ø1	-.14399E ØØ	.4Ø784E-Ø1	.3Ø718E ØØ
/UBIC	-.45942E-Ø1	-.24476E-Ø1	.1Ø232E ØØ	.19525E-Ø1	.3Ø215E-Ø1	.13431E-Ø1

TABLE B-11.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW RCHH
(10 KNOT CASE)

USER IDENTIFICATION : SCAT

TRIMMED AIRSPEED = 1Ø.Ø KNOTS
RELATIVE VELOCITY = 16.9 FT/SEC
ANGLE OF ATTACK = 5.48 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = .3 LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

YAW – RCHH
PITCH, ROLL – IVC
COLLECTIVE – IVC

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	-.84141E-Ø2	-.1715ØE Ø1	.23395E ØØ	-.43176E Ø1	.12215E Ø[illegible]	-.16289E ØØ
/QBIC	.58349E Ø1	.13814E Ø1	.2621ØE Ø1	-.37318E Ø1	-.43447E Ø1	-.33Ø27E ØØ
/RBIC	-.11965E ØØ	.1Ø353E Ø2	.2613ØE ØØ	.27133E Ø1	-.66843E-Ø1	-.11946E Ø2
/VBIC	.41Ø83E-Ø2	-.469Ø3E-Ø1	.6Ø928E-Ø1	-.51Ø36E-Ø1	-.51666E-Ø2	.144ØØE-Ø1
/WBIC	.12442E ØØ	.26Ø23E-Ø1	-.2Ø244E Ø1	-.16Ø92E-Ø1	-.12794E-Ø1	.97366E-Ø1
/DAP	-.31Ø99E ØØ	.1Ø65ØE Ø1	-.1Ø222E ØØ	.21Ø86E Ø1	.23ØØ4E ØØ	.63899E-Ø1
/DEP	[illegible]	-.28499E ØØ	[illegible]	[illegible]	[illegible]	[illegible]
/DRP	.21426E-Ø1	-.25176E Ø1	-.12844E-Ø1	-.7Ø7Ø8E ØØ	.16Ø72E-Ø1	.2859ØE Ø1
/DCP	.4928ØE ØØ	.16798E ØØ	-.768Ø1E Ø1	-.112ØØE ØØ	-.46411E-Ø1	.47998E ØØ
/UBIC	-.487Ø2E-Ø1	.27763E-Ø1	.3Ø543E-Ø1	.1Ø231E ØØ	.382Ø4E-Ø1	-.13744E-Ø1

TABLE ?-12.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW RCHH
(20 KNOT CASE)

USER IDENTIFICATION : SCAT

TRIMMED AIRSPEED = 2Ø.Ø KNOTS
RELATIVE VELOCITY = 33.8 FT/SEC
ANGLE OF ATTACK = 5.82 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = 1.4 LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

YAW RCHH
PITCH, ROLL – IVC
COLLECTIVE – IVC

		STEP SIZE	UNITS	SCALE FACTOR
INDEPENDENT VARIABLES	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

		UNITS	SCALE FACTOR
DEPENDENT VARIABLES	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.19572E-Ø1	-.18427E Ø1	.33325E ØØ	-.43415E Ø1	.11315E ØØ	-.18Ø9ØE ØØ
/QBIC	.57641E Ø1	.1432ØE Ø1	.41881E Ø1	-.37118E Ø1	-.43664E Ø1	-.38293E ØØ
/RBIC	-.1Ø424E ØØ	.1ØØØ8E Ø2	.29859E ØØ	.26347E Ø1	-.16556E-Ø1	-.11981E Ø2
/VBIC	.51271E-Ø2	-.46388E-Ø1	.58255E-Ø1	-.47949E-Ø1	-.63947E-Ø2	.18Ø4ØE-Ø1
/WBIC	.12196E ØØ	-.61927E-Ø2	-.21228E Ø1	-.22974E-Ø1	-.96346E-Ø2	.78556E-Ø1
/DAP	-.31Ø97E ØØ	.1Ø437E Ø1	-.17892E ØØ	.19596E Ø1	.23ØØ4E ØØ	.63899E-Ø1
/DEP	-.91196E ØØ	-.29448E ØØ	-.60478E ØØ	.58047E ØØ	.62132E ØØ	.20499E-Ø1
/DRP	.16624F-Ø1	-.25Ø44E Ø1	-.22151E-Ø1	-.7Ø921E ØØ	.44386E-Ø2	.29437E Ø1
/DCP	.45598E ØØ	.25598E-Ø1	-.7632ØE Ø1	-.12159E ØØ	-.2Ø8Ø1E-Ø1	.41539E ØØ
/UBIC	-.75737E-Ø1	-.9Ø333E-Ø2	.1Ø94ØE ØØ	.4515ØE-Ø1	.36378E-Ø1	-.15819E-Ø1

TABLE B-13.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW RCHH (30 KNOT CASE)

USER IDENTIFICATION : SCAT

YAW – RCHH
PITCH, ROLL – IVC
COLLECTIVE – IVC

TRIMMED AIRSPEED = 3Ø.Ø KNOTS
RELATIVE VELOCITY = 5Ø.7 FT/SEC
ANGLE OF ATTACK = 4.59 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = 3.Ø LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.33Ø85E-Ø1	-.19477E Ø1	.53494E ØØ	-.43866E Ø1	.1Ø615E ØØ	-.19225E ØØ
/QBIC	.57837E Ø1	.15382E Ø1	.57259E Ø1	-.373Ø7E Ø1	-.43371E Ø1	-.4559ØE ØØ
/RBIC	-.19213E ØØ	.99653E Ø1	.35993E ØØ	.25955E Ø1	.23733E-Ø1	-.12257E Ø2
/VBIC	.68978E-Ø2	-.69671E-Ø1	.517Ø9E-Ø1	-.51Ø Ø9E-Ø1	-.57128E-Ø2	.21513E-Ø1
/WBIC	.11963E ØØ	-.16226E-Ø1	-.2289ØE Ø1	-.2842ØE-Ø1	-.13587E-Ø2	.62147E-Ø1
/DAP	-.31Ø97E ØØ	.1Ø437E Ø1	-.2684ØE ØØ	.19596E Ø1	.23Ø63E ØØ	.53249E-Ø1
/DEP	-.[illegible]E ØØ	-.3Ø398E ØØ	-.1[illegible]E Ø1	.6Ø32[illegible]E ØØ	.[illegible]E ØØ	.4Ø[illegible]49E-Ø1
/DRP	.36612E-Ø1	-.24959E Ø1	-.33797E-Ø1	-.69859E ØØ	-.5Ø615E-Ø2	.3Ø2ØØE Ø1
/DCP	.43Ø37E Ø3	-.56Ø3ØE-Ø2	-.8Ø476E Ø1	-.1328ØE ØØ	-.64Ø87E-Ø2	.36638E ØØ
/UBIC	-.1Ø384E ØØ	-.38349E-Ø1	.88336E-Ø1	.16Ø34E-Ø1	.37969E-Ø1	-.13Ø42E-Ø1

TABLE B-14.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW RCHH (40 KNOT CASE)

USER IDENTIFICATION : SCAT

YAW – RCHH
PITCH, ROLL – IVC
COLLECTIVE – IVC

TRIMMED AIRSPEED = 4Ø.Ø KNOTS
RELATIVE VELOCITY = 67.6 FT/SEC
ANGLE OF ATTACK = 3.37 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = [illegible]94Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = 5[illegible] LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

INDEPENDENT VARIABLES

	STEP SIZE	UNITS	SCALE FACTOR
PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES

	UNITS	SCALE FACTOR
FTX	LBS.	.1ØØØØE Ø1
FTY	LBS.	.1ØØØØE Ø1
FTZ	LBS.	.1ØØØØE Ø1
TTL	FTLB	.1ØØØØE Ø1
TTM	FTLB	.1ØØØØE Ø1
TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.46563E-Ø1	-.2Ø526E Ø1	.73656E ØØ	-.44315E Ø1	.99157E-Ø1	-.2Ø358E ØØ
/QBIC	.58Ø36E Ø1	.16443E Ø1	72627E Ø1	-.37495E Ø1	-.43Ø78E Ø1	-.52883E ØØ
/RBIC	-.28ØØ8E ØØ	.99225E Ø1	.42123E ØØ	.25563E Ø1	.64Ø23E-Ø1	-.14Ø38E Ø2
/VBIC	.8555ØE-Ø2	-.9303ØE-Ø1	.45599E-Ø1	-.54Ø9ØE-Ø1	-.6ØØ36E-Ø2	.24767E-Ø1
/WBIC	.12156E ØØ	-.23Ø52E-Ø1	-.24528E Ø1	-.3Ø972E-Ø1	.65342E-Ø2	.45975E-Ø1
/DAP	-.31Ø97E ØØ	.1Ø437E Ø1	-.35784E ØØ	.19596E Ø1	.23ØØ4E ØØ	.42599E-Ø1
/DEP	-.67398E ØØ	-.31347E ØØ	-.18542E Ø1	.6Ø79ØE ØØ	.81661E ØØ	.532ØØE-Ø1
/DRP	.56657E-Ø1	-.24593E Ø1	-.45319E-Ø1	-.67997E ØØ	-.14721E-Ø1	.35132E Ø1
/DCP	.4Ø478E ØØ	-.36792E-Ø1	-.84637E Ø1	-.14399E ØØ	.79834E-Ø2	.3168ØE ØØ
/UBIC	-.74Ø32E-Ø1	-.32Ø72E-Ø1	.734Ø9E-Ø1	.17474E-Ø1	.34236E-Ø1	-.77977E-Ø2

TABLE P-15.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW RCHH
(50 KNOT CASE)

USER IDENTIFICATION : SCAT

YAW – RCHH
PITCH, ROLL – IVC
COLLECTIVE – IVC

TRIMMED AIRSPEED = 5Ø.Ø KNOTS
RELATIVE VELOCITY = 84.4 FT/SEC
ANGLE OF ATTACK = 3.55 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = 8.5 LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

INDEPENDENT VARIABLES		STEP SIZE	UNITS	SCALE FACTOR
	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

DEPENDENT VARIABLES		UNITS	SCALE FACTOR
	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.32776E-Ø1	-.2Ø613E Ø1	.87937E ØØ	-.44315E Ø1	.94423E-Ø1	-.22414E ØØ
/QBIC	.56655E Ø1	.16324E Ø1	.9Ø28ØE Ø1	-.37245E Ø1	-.43366E Ø1	-.23Ø28E Ø1
/RBIC	-.31Ø93E ØØ	.9829ØE Ø1	.36794E ØØ	.24197E Ø1	.13867E ØØ	-.13754E Ø2
/VBIC	.77986E-Ø2	-.1Ø651E ØØ	.41785E-Ø1	-.54164E-Ø1	-.6Ø826E-Ø2	.27ØØ4E-Ø1
/WBIC	.12466E ØØ	-.32721E-Ø1	-.257Ø8E Ø1	-.31Ø43E-Ø1	.14Ø25E-Ø1	.46Ø25E-Ø1
/DAP	-.3Ø353E ØØ	.1Ø5ØØE Ø1	-.328Ø4E ØØ	.19596E Ø1	.23216E ØØ	.38339E-Ø1
/DEP	-.84546E ØØ	-.31349E ØØ	-.17411E Ø1	.6Ø798E ØØ	.61986E ØØ	.3971ØE ØØ
/DRP	.67994E-Ø1	-.23969E Ø1	-.26Ø59E-Ø1	-.65161E ØØ	-.34554E-Ø1	.34ØØ1E Ø1
/DCP	.4Ø796E ØØ	-.6Ø791E-Ø1	-.8816ØE Ø1	-.14399E ØØ	.4Ø784E-Ø1	.3Ø718E ØØ
/UBIC	-.45942E-Ø1	-.24476E-Ø1	.1Ø231E ØØ	.19525E-Ø1	.3Ø215E-Ø1	.13434E-Ø1

TABLE B-16.- STABILITY DERIVATIVE MATRIX WITH AUGMENTATION ADDED, YAW RCHH
(60 KNOT CASE)

USER IDENTIFICATION : SCAT

TRIMMED AIRSPEED = 6Ø.Ø KNOTS
RELATIVE VELOCITY = 1Ø1.3 FT/SEC
ANGLE OF ATTACK = 3.74 DEG
FLIGHT PATH ANGLE = .ØØ DEG
WEIGHT = 394Ø. LBS
MASS = 122.4 SLUGS   WING AREA = .Ø FT2
SPAN = 4.3 FT   CHORD = 27.7 FT
RHO = .23736E-Ø2 SLUG/FT3   QBAR = 12.2 LB/FT2
IXX = 1Ø28. SLUG-FT2   IZZ = 2228. SLUG-FT2
IYY = 2939.   IXZ = 363.

YAW – RCHH
PITCH, ROLL – IVC
COLLECTIVE – IVC

		STEP SIZE	UNITS	SCALE FACTOR
INDEPENDENT VARIABLES	PBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	QBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	RBIC	.5ØØØØE Ø1	R/S	.17453E-Ø1
	VBIC	.5ØØØØE Ø1	FPS	.1ØØØØE Ø1
	WBIC	.5ØØØØE ØØ	FPS	.1ØØØØE Ø1
	DAP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DEP	.5ØØØØE ØØ	INCH	.1ØØØØE Ø1
	DRP	.3ØØØØE Ø1	INCH	.1ØØØØE Ø1
	DCP	.1ØØØØE Ø2	INCH	.1ØØØØE Ø1
	UBIC	.4ØØØØE Ø1	FPS	.1ØØØØE Ø1

		UNITS	SCALE FACTOR
DEPENDENT VARIABLES	FTX	LBS.	.1ØØØØE Ø1
	FTY	LBS.	.1ØØØØE Ø1
	FTZ	LBS.	.1ØØØØE Ø1
	TTL	FTLB	.1ØØØØE Ø1
	TTM	FTLB	.1ØØØØE Ø1
	TTN	FTLB	.1ØØØØE Ø1

EACH COLUMN REPRESENTS ONE OF THE 6 DEPENDENT VARIABLES.
EACH ROW REPRESENTS ONE OF THE 1Ø INDEPENDENT VARIABLES.

	FTX	FTY	FTZ	TTL	TTM	TTN
/PBIC	.18978E-Ø1	-.2Ø7ØØE Ø1	.1Ø221E Ø1	-.44315E Ø1	.89699E-Ø1	-.24467E ØØ
/QBIC	.55277E Ø1	.162Ø4E Ø1	.1Ø792E Ø2	-.36995E Ø1	-.43657E Ø1	-.4Ø767E Ø1
/RBIC	-.34177E ØØ	.97354E Ø1	.31464E ØØ	.22832E Ø1	.21331E ØØ	-.13468E Ø2
/VBIC	.7Ø926E-Ø2	-.12ØØ1E ØØ	.37663E-Ø1	-.5424ØE-Ø1	-.61276E-Ø2	.29245E-Ø1
/WBIC	.125Ø9E ØØ	-.42581E-Ø1	-.2682ØE Ø1	-.31317E-Ø1	.216Ø7E-Ø1	.45478E-Ø1
/DAP	-.296Ø9E ØØ	.1Ø564E Ø1	-.29823E ØØ	.19596E Ø1	.23428E ØØ	.34Ø8ØE-Ø1
/DEP	-.81698E ØØ	-.31349E ØØ	-.21277E Ø1	.6Ø798E ØØ	.62318E ØØ	.741ØØE ØØ
/DRP	.79333E-Ø1	-.23346E Ø1	-.67987E-Ø2	-.62329E ØØ	-.54387E-Ø1	.32868E Ø1
/DCP	.41116E ØØ	-.8479ØE-Ø1	-.9168ØE Ø1	-.14399E ØØ	.73584E-Ø1	.29758E ØØ
/UBIC	-.57418E-Ø1	-.18976E-Ø1	.89115E-Ø1	.22Ø12E-Ø1	.29867E-Ø1	.25372E-Ø1

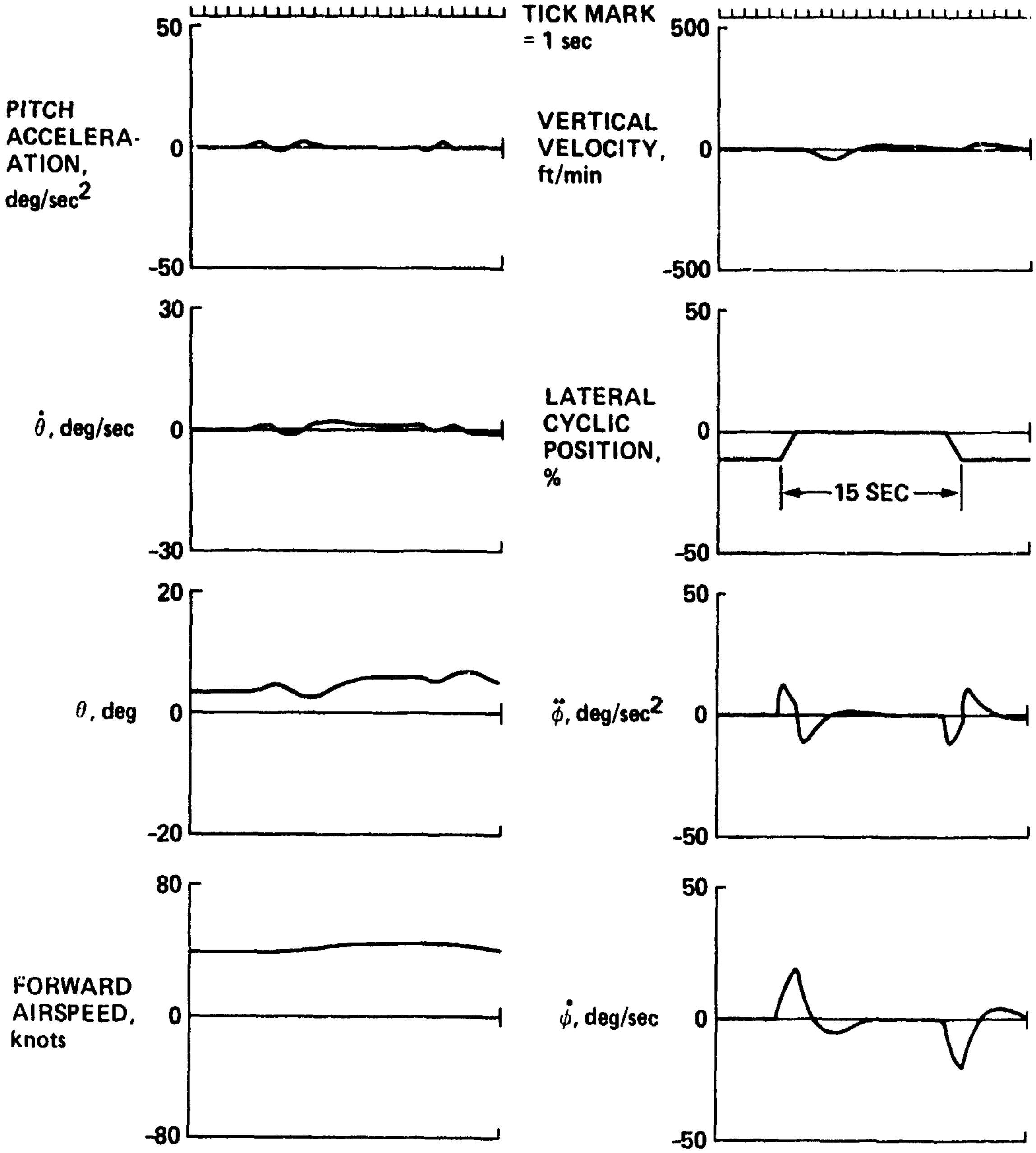


Figure B7.- Time history for 1-in., ramped longitudinal cyclic input (15 sec) - inertial velocity command system.

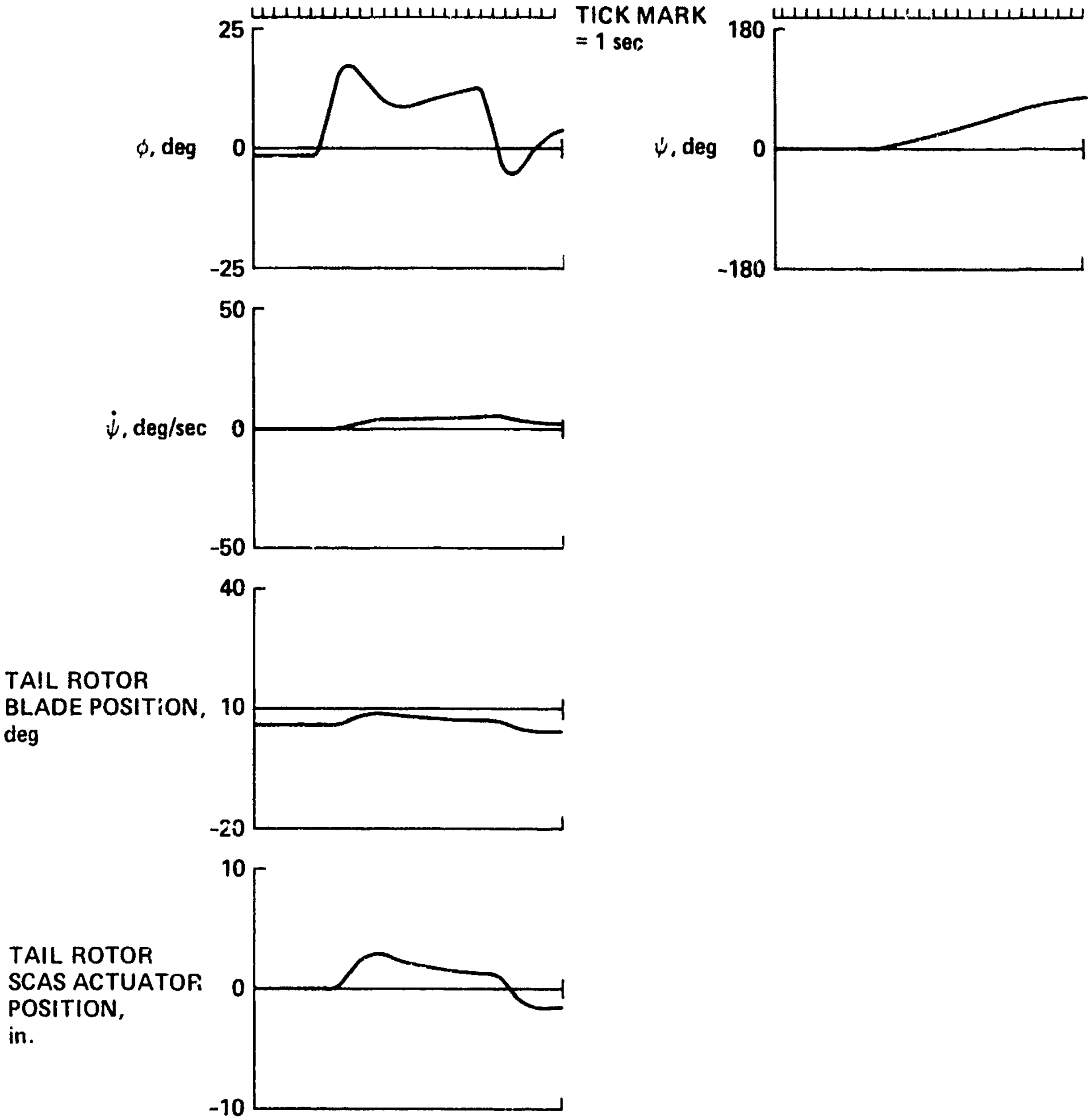


Figure B7.- Concluded.

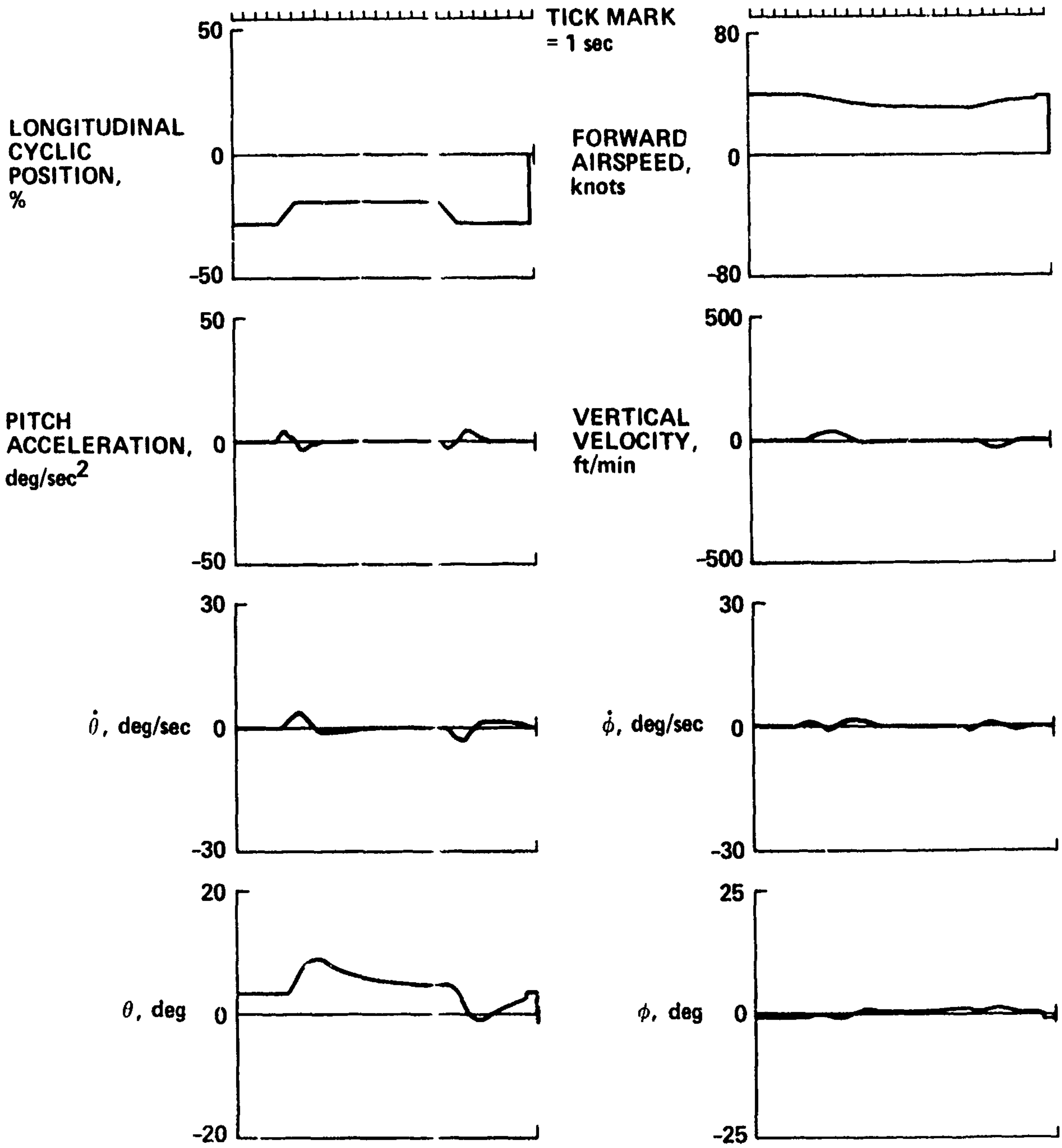


Figure B8.- Time history for -in., ramped lateral cyclic input (15 sec) - inertial velocity command system.

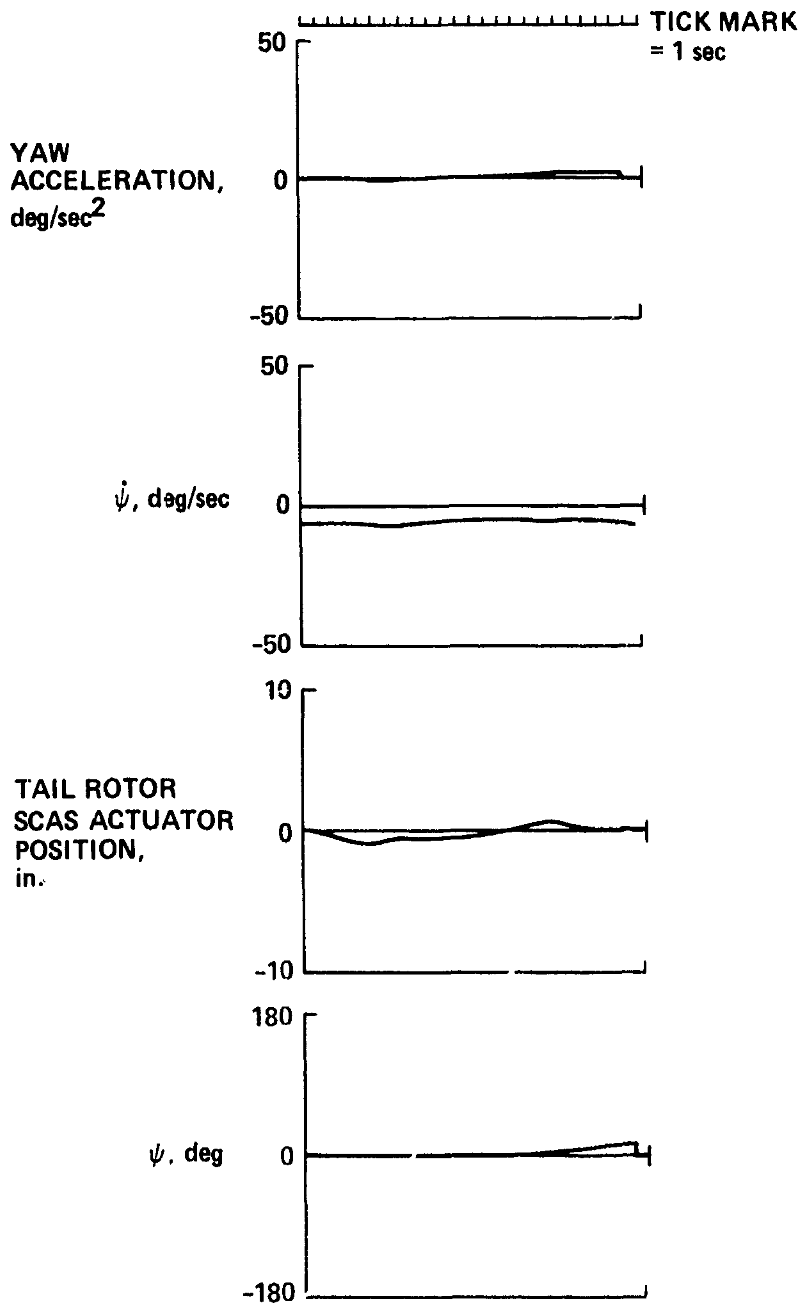


Figure B8.- Concluded.

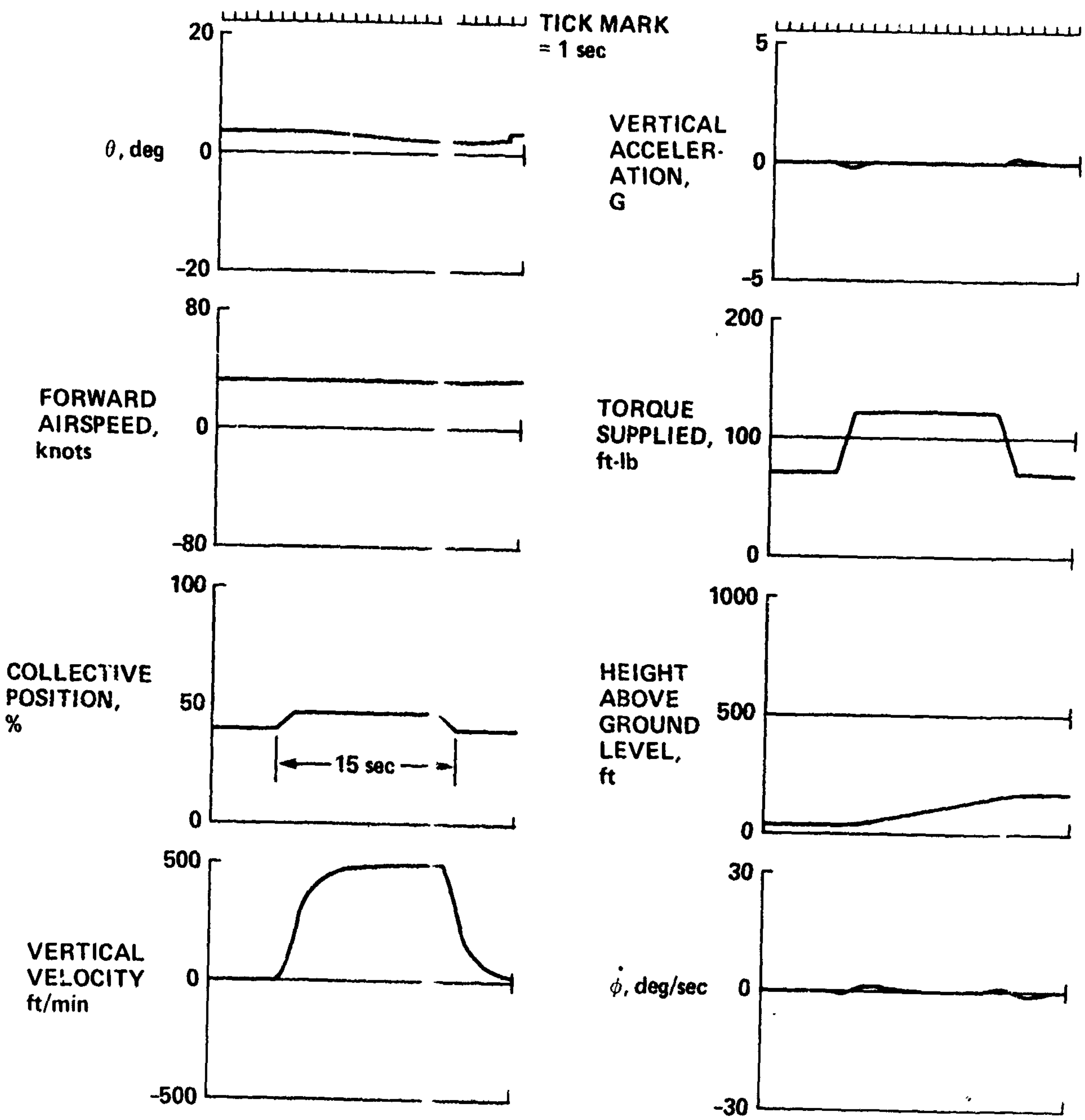


Figure B9.- Time history fo·· 1-in., ramped collective input (15 sec) - inertial velocity command system.

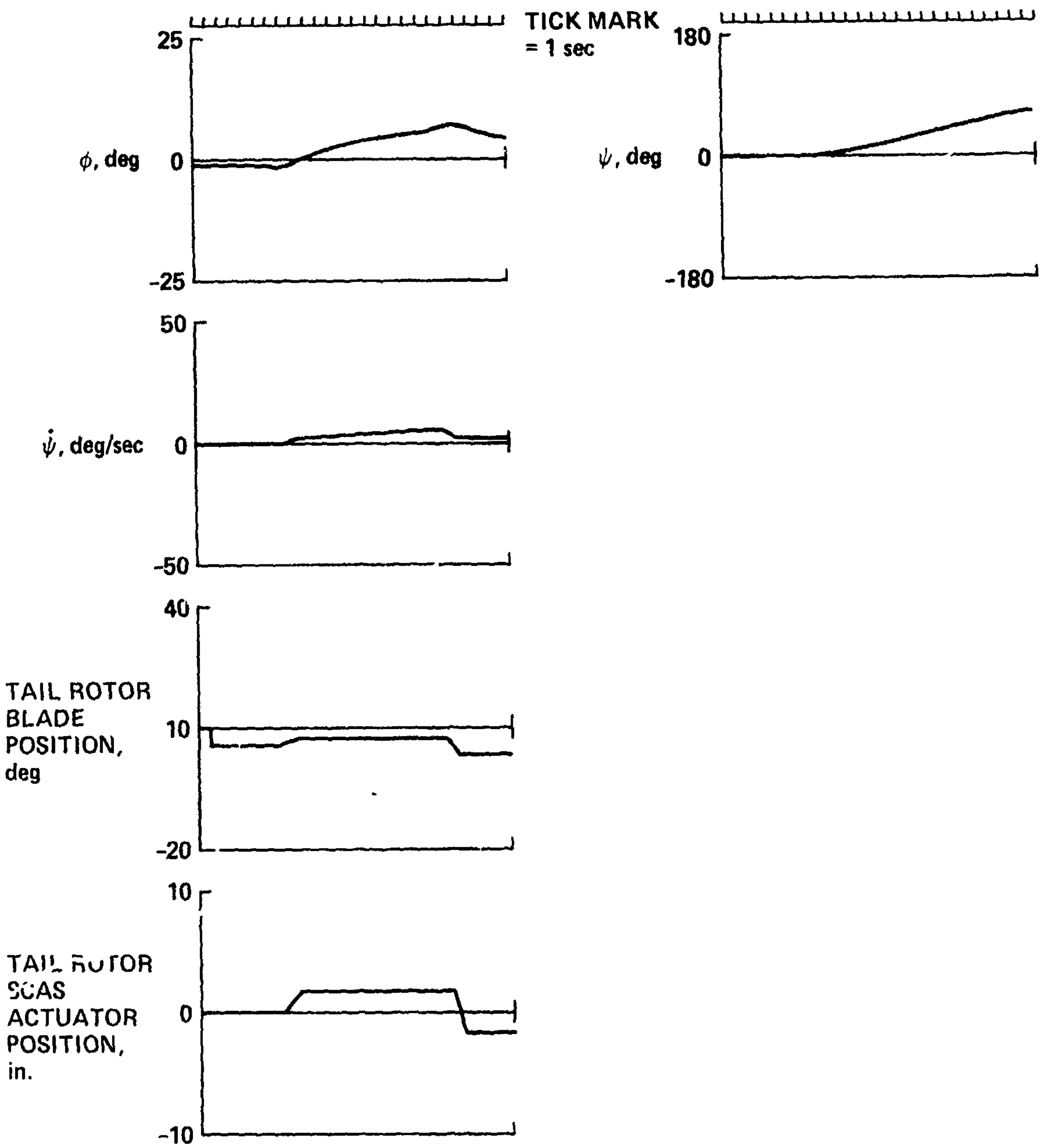


Figure B9.- Concluded.

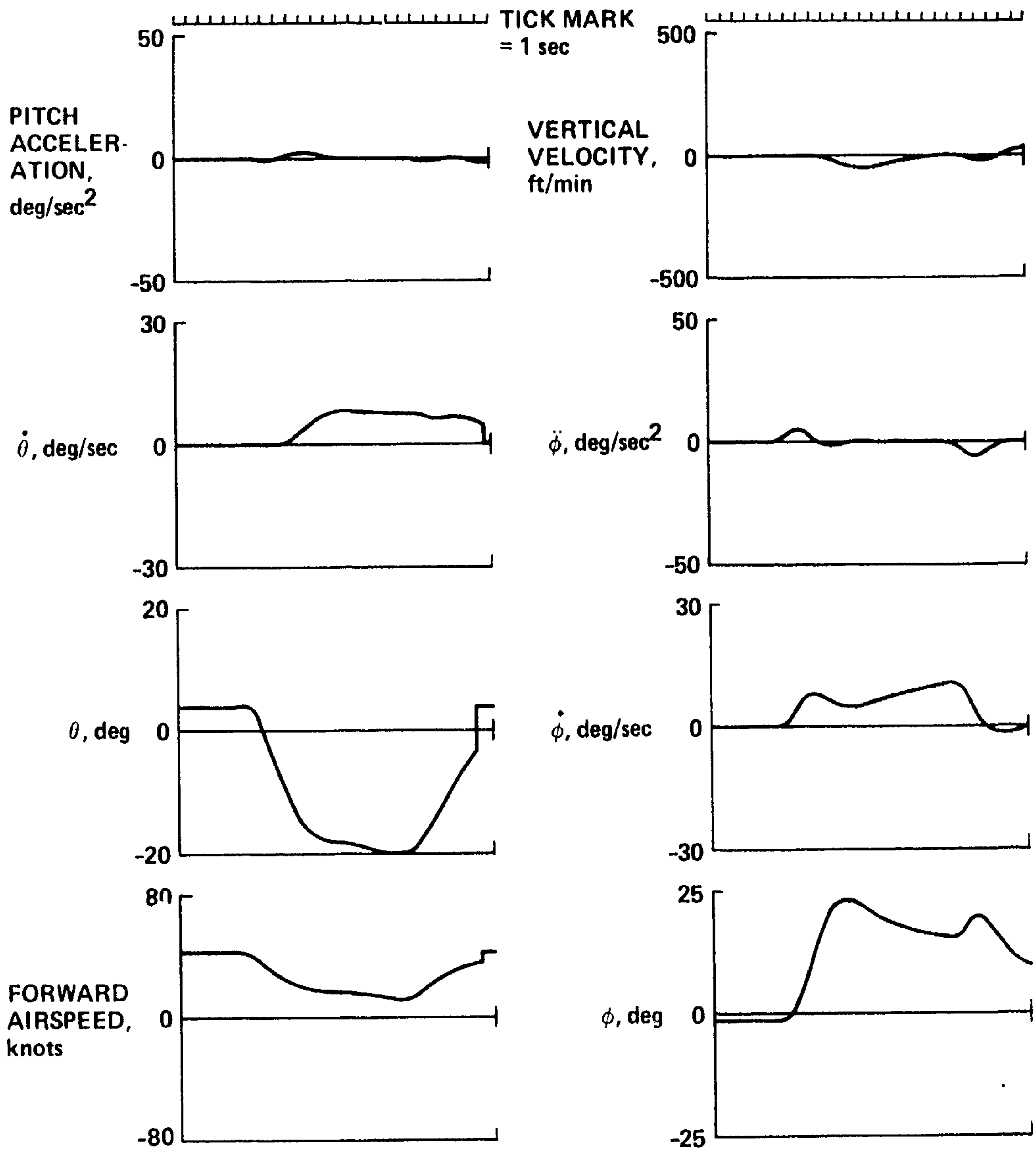


Figure B10.- Time history for 1-in., ramped pedal input (15 sec) - yaw axis SCAS.

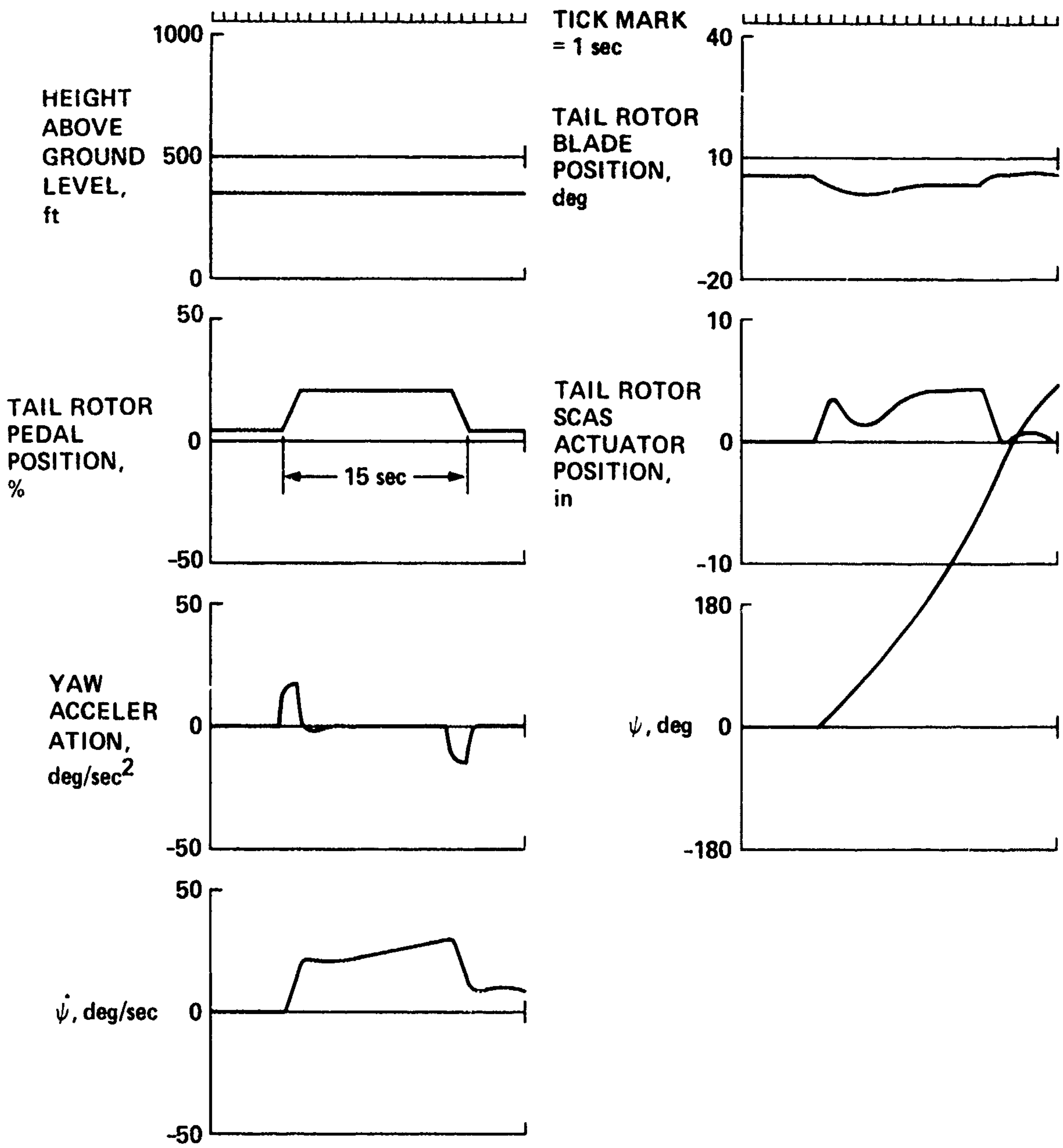


Figure B10.- Concluded.

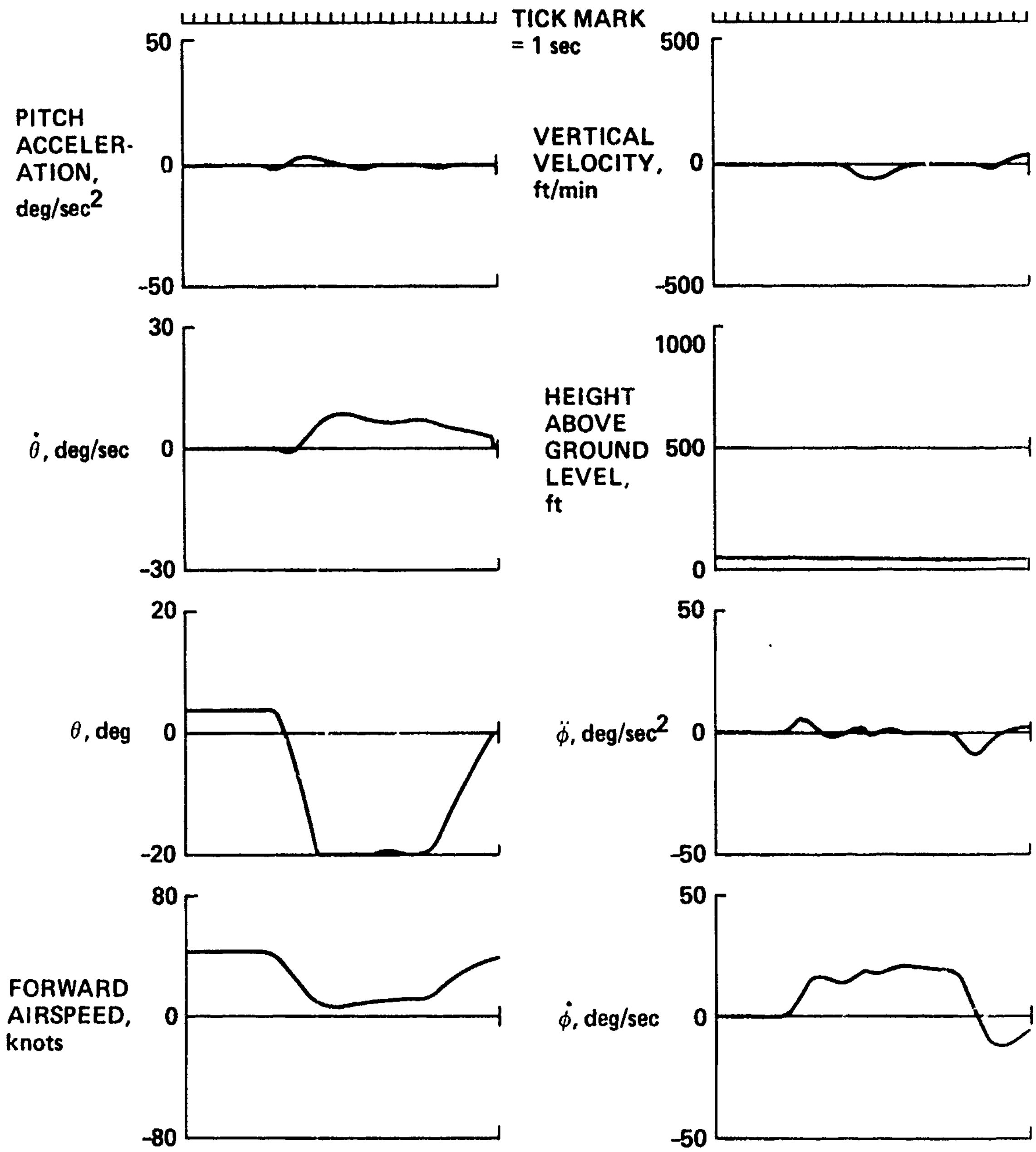


Figure B11.- Time history for 1-in., ramped pedal input (15 sec) - rate command heading hold.

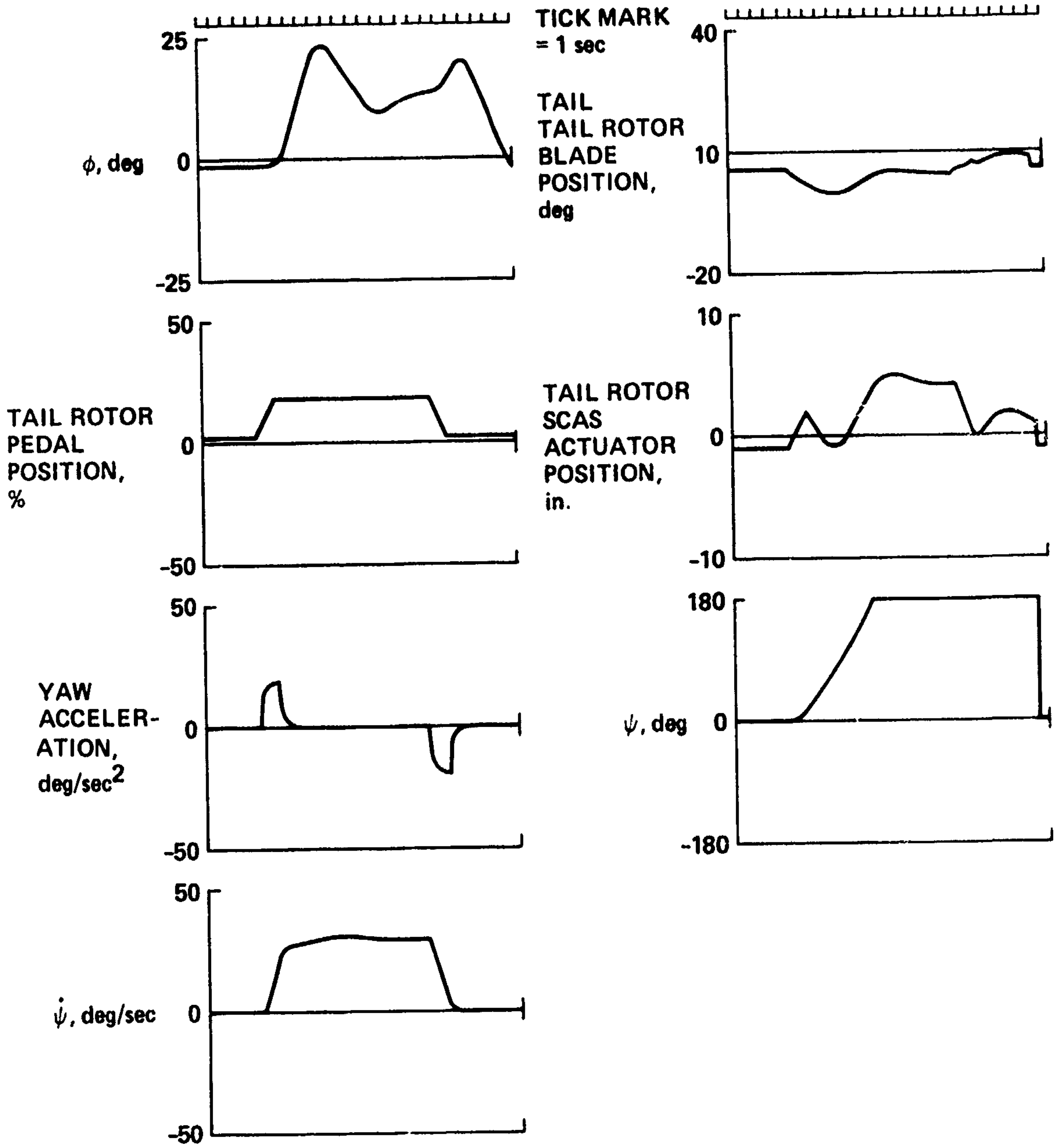


Figure B11.- Concluded.

APPENDIX C

COCKPIT CONFIGURATION DATA

A listing of the control characteristics that were implemented for the simulation is given in Table C-1. The actual set-up of the cockpit for the conduct of the experiment is shown in figure C1.

TABLE C-1.- AIRCRAFT CONTROL SYSTEM CHARACTERISTICS

	Collective system	Longitudinal cyclic system	Lateral cyclic system	Directional system
Control travel	10.65 in.	10.66 in.	8.54 in.	6.50 in.
Swash-plate travel	1° full down 17° full up	11° forward 11° aft	6.0° left 6.0° right	
Rotor blade travel at 0.75R	16°	22°	12°	40°
Rotor gearing	1.5°/in.	2.06°/in.	1.43°/in.	6.15°/in.
Control breakout force (zero friction)	2.0 lb	0.5 lb	0.5 lb	4.0 lb
Control-force gradient	0.0 lb/in.	1.05 lb/in.	0.68 lb/in.	3.5 lb/in.
Limit-control forces	3.0 lb	6.1 lb	3.4 lb	15.0 lb

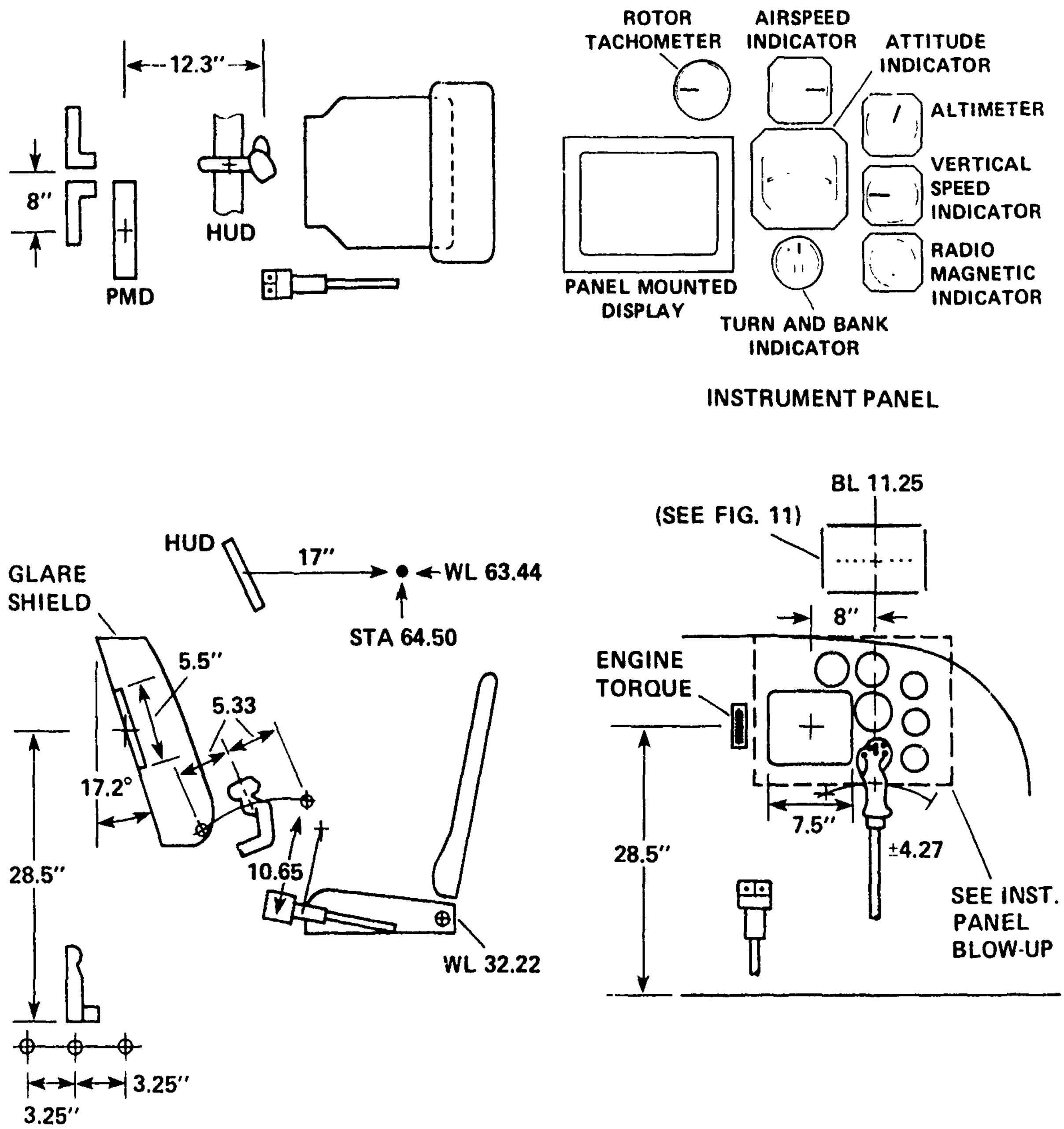


Figure C1.- SCAT cockpit general arrangement.

APPENDIX D

PILOT INSTRUCTIONS

BRIEFING
(To be read by pilot)

The mission will begin at point A, with the aircraft at 50 ft AGL and 40 knots, and the panel-mounted display (PMD) in the Transition mode. There may be wind and turbulence.

NOE. Fly through the canyon at 40 ±5 knots, staying as close to the ground as possible (no higher than 50 ft AGL).

DECEL. After crossing the last berm, decelerate and switch the PMD to Hover at 10 to 15 knots. Come to a full stop within 10 ft of the center of the hover area, at 10 ±2 ft AGL and pointing North ±5°.

LOW-TURNS. Switch the PMD to Bob-up. Turn left and stop at 180 ±5°. Then turn right and stop at North ±5°. Use a constant turn rate, not to exceed 90° in 4 sec, and stay within 5 ft of the initial hover point at 10 ±2 ft AGL. At the end of the low turns, say "mark" and squeeze the trigger switch to the first detent. (CAUTION: second detent disengages simulation.)

BOB-UP. With the PMD still in Bob-up, bob-up to 80 ±10 ft AGL. Stay within 5 ft of the initial hover point, pointing North ±5°. Say "mark" and squeeze the trigger switch to the first detent.

HIGH-TURNS. With the PMD still in Bob-up, turn left and stop at 180 ±5°. Then turn right and stop at North ±5°. Use a constant turn rate, not to exceed 90° in 4 sec, and stay within 5 ft of the initial hover point at 80 ±10 ft AGL. At the end of the high-turns, switch the PMD to Hover.

FIRE-CONTROL. With the PMD still in Hover, turn right maintaining 80 ±10 ft AGL. Stop at the ZSU-23 (at 120-130°).

Switch the PMD to Bob-up, and stay within 5 ft of the current hover point at 80 ±10 ft AGL. Watch for the target which will be flying from left to right, or right to left. It may not appear right away. As soon as you see the target, and not before, switch the HUD to Fire Control.

Using the HUD, put the sight pipper on the target. A tone will sound, and the missile-launch-constraints box will appear on the HUD. Keep the target inside the launch-constraints box until the tone changes in pitch, then press the fire button. The missile-launch box will flash, indicating a hit. Stay within 10 ft of

the hover point and at 80 ±20 ft AGL throughout target-acquisition. If you do not fire within 15 sec, a pulsating tone will sound and you will be scored as having been shot down. This will also happen if you fire before acquiring the target, exceed 100 ft AGL, or crash into a tree or the ground during tracking.

Ratings. Assign a C-H rating to the NOE, deceleration, low-hover turns, high-hover turns, and fire-control segments of the mission. You do not have to rate the bob-up maneuver.

APPENDIX E

DATA ACQUISITION REQUIREMENTS

Tables E-1 through E-3 delineate the variable data collected on the three strip charts available for use throughout the experiment. Table E-4 lists the immediate post-run aircraft performance data to include preliminary statistics that were provided from a Versatec line printer. Table E-5 lists when the different phases of data collection were initiated. Table E-6 lists the mission outcome codes used to categorize each air-to-air engagement. Figure E1 represents a graphical time line representation of the complete fire control task.

TABLE E-1.- STRIP CHART DATA VARIABLES (NO. 1)

Parameter	Mnemonic	Full scale/units	Polarity
1. Longitudinal cyclic position	DELE	±50%	+ Aft
2. Pitch angular acceleration	QBDDG	±50°/sec^2	+ Nose up
3. Pitch rate	QBDG	±30°/sec	+ Nose up
4. Pitch attitude	THET	±20°	+ Nose up
5. Airspeed	UBKTS	-20 to +60 knots	
6. Collective control position	DELC	0-100%	+ Up
7. Vertical velocity	HD	±500 rpm	+ Up
8. Vertical acceleration	HDDG	±5 g's	+ Up

TABLE E-2.- STRIP CHART DATA VARIABLES (NO. 2)

Parameter	Mnemonic	Full scale/units	Polarity
1. rpm	OMEGA	360-410 rpm	
2. Δrpm	DOMEGA	±20	+ High
3. Torque Q	TORQ	0-200 ft-lb	+ >
4. Radar altitude	HAGL	0-100 ft	+ >
5. Lateral cyclic stick position	DELA	±50%	+ RT
6. Roll angular acceleration	PBDDG	±50°/sec^2	+ RT
7. Roll rate	PBDG	±30°/sec	+ RT
8. Roll attitude	PHI	±25°	+ RT

TABLE E-3.- STRIP CHART DATA VARIABLES (NO. 3)

Parameter	Mnemonic	Full scale/units	Polarity
1. Directional pedal position	DELR	±50%	+ RT
2. Yaw angular acceleration	RBDDG	±50°/sec^2	+ RT
3. Yaw rate	RBDG	±50°/sec	+ RT
4. Yaw rate	RBDG	±10°/sec	+ RT
5. θ_{TR}	THETTR	-20° to +40°	
6. Yaw SCAS actuator movement	DELTR	±10 in.	+ RT
7. ψ-heading error	PSII	±50°	+ RT
8. θ-elevation error	THETI	±20°	+ RT

TABLE E-4.- END OF RUN VERSATEC DATA
(Minimum value, maximum value, rms, mean, σ, N sample)

Variables	Mission phase				
	NOE	DECEL	IGE TURN	OGE TURN	TARGET
Height above ground, ft	✓	✓	✓	✓	✓
Longitudinal velocity, ft/sec	✓	✓			✓
Lateral velocity, ft/sec	✓	✓			✓
Heading, deg	✓	✓	✓	✓	✓
Cyclic lateral position, in.	✓	✓	✓	✓	✓
Cyclic longitudinal position, in.	✓	✓	✓	✓	✓
Collective position, in.	✓	✓	✓	✓	✓
Pedal position, in.	✓	✓	✓	✓	✓
Attitude rate, deg/sec		✓			
Pitch angle, deg		✓	✓	✓	✓
Y-hover error, ft			✓	✓	✓
X-hover error, ft			✓	✓	✓
Radial hover error[a]			✓	✓	✓
Heading error, deg		✓			
Y-hover velocity, ft/sec			✓	✓	✓
X-hover velocity, ft/sec			✓	✓	✓
Yaw rate, ft/sec	✓	✓	✓	✓	✓
Yaw acceleration, ft/sec[b]	✓	✓	✓	✓	✓
Azimuth sighting error, deg					✓
Elevation sighting error, deg					✓
Time[b]	✓	✓	✓	✓	✓
Mission failure code[c]					✓
Target direction, ±					✓
Target slant range					✓
Torque, ft-lb	✓	✓	✓	✓	✓
SAS actuator, deg	✓	✓	✓	✓	✓
Lateral component of wind, knots	✓	✓	✓	✓	✓

[a]Radial hover error calculations are explained in detail on page 146.
[b]Time marking points are shown in table E-5 and figure E-1.
[c]Mission failure codes are described in table E-6.

TABLE E-5.-YAW CONTROL SIMULATION EVENT MARKERS

Event No.	Flight task	Start time marker	End time marker	Task-required display mode(s)
1	NOE	Start of RUN	Last berm	Transition
2	Decelerate/stop	Last berm	B-U display (1)	Transition → Hover
3	Low turns	B-U display (1)	Marker (1)	Bob-Up
4	Bob-Up (B-U)	Marker (1)	Marker (2)	Bob-Up
5	High turns	Marker (2)	Hover display (2)	Bob-Up

TABLE E-6.- AIR-TO-AIR TARGET ACQUISITION MISSION OUTCOME CODES

Code 1 = Missile fired/target in launch-constraints-box (LCB) = Hit
2 = Missile fired/target not in LCB = Miss
3 = Exceeded time limit for target-acquisition task + Shot Down
4 = Exceeded altitude limit for target-acquisition task = Shot Down
5 = Ownship contacted terrain during T-A task = Crashed
9 = F/c logic or CGI Problem, but reaction 2 data valid
0 = F/c logic or CGI Problem, and all phase 6 data invalid

DEFINITIONS OF HOVER-ERROR MEASURES FOR YAW-CONTROL STUDY

Vehicle location at start of maneuver: X_o, Y_o

Longitudinal hover error: $(EXH)_i = x_i - x_o$

Lateral hover error: $(EYH)_i = y_i - y_o$

Radial hover error: $(ERH)_i = \sqrt{(EXH)_i^2 + (EYH)_i^2}$

Circular error radius: $(CER)_i = \sqrt{[(EXH)_i - \overline{EXH}]^2 + [(EYH)_i - \overline{EYH}]^2}$

where $\overline{EXH} = \dfrac{\tilde{\varepsilon}(EXH)_i}{N}$ and $\overline{EYH} = \dfrac{\tilde{\varepsilon}(EYH)_i}{N}$

Median radial hover error (50 ERH): Value of $(ERH)_i$ which encompasses 50% of the $(ERH)_i$'s; that is, with the radial hover errors ranked according to size, the median $(ERH)_i$ is that radius at or below which 50% of the $(ERH)_i$'s lie.

Median circular error radius (50 CER): Value of $(CER)_i$ which encompasses 50% of $(CER)_i$'s.

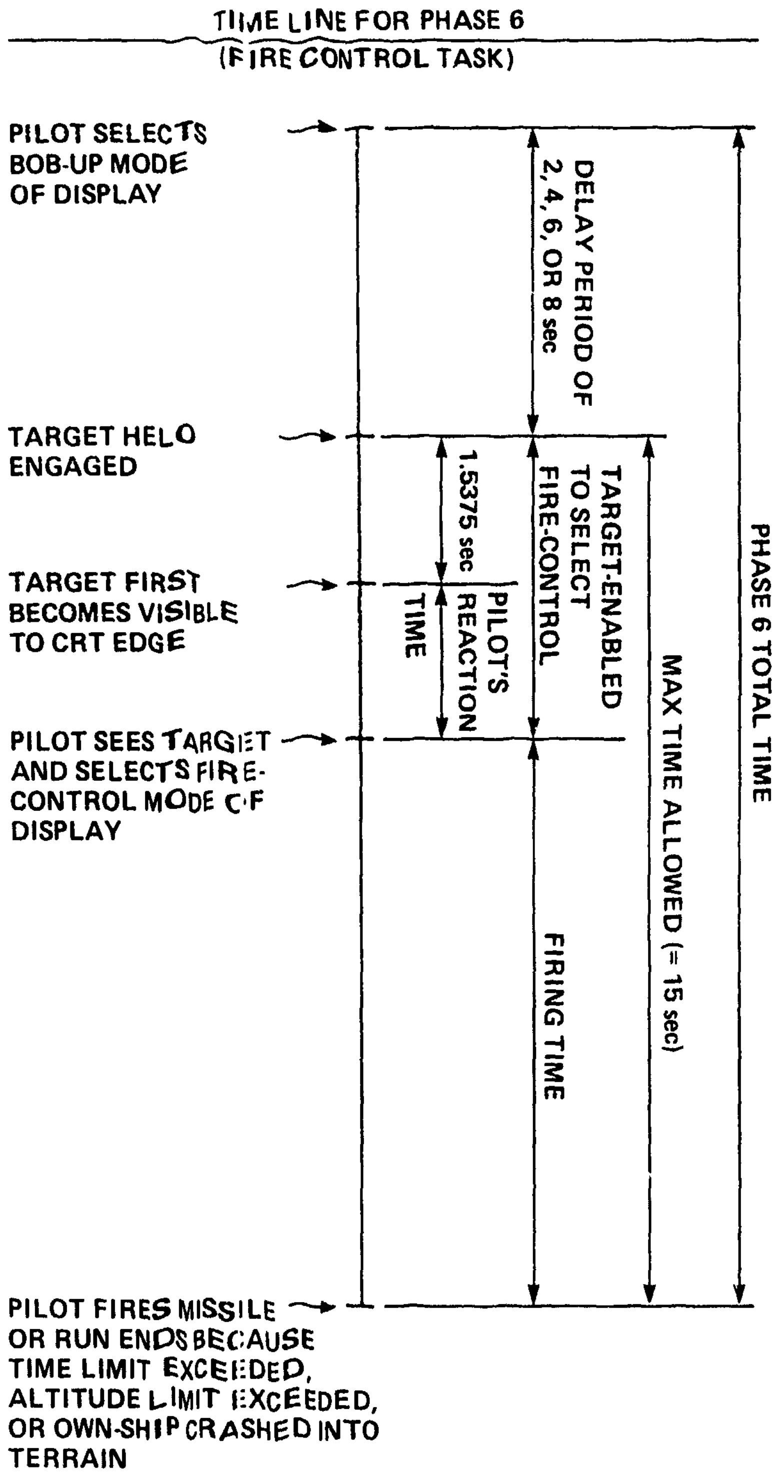


Figure E1.- Time line sequence for air-to-air target acquisition task.

APPENDIX F

PILOT RATING DATA

Tables F-1 through F-5 represent the individual and averaged pilot ratings for each task and tested configuration. Tables F-6 through F-10 represent a correlation analysis conducted on the pilot ratings of the primary test configurations to enable the indexing of pilot sensitivity.

TABLE F-1.- PILOT RATINGS FOR NOE FLIGHT TASK

Test configuration	p1	p2	p3	HQR p4	n	$\bar{x}$	sd
3	5.0	7.0	5.0	6.0	4	5.750	0.829
4	5.0	4.5	3.0	3.5	4	4.000	.791
5	4.0	6.0	3.0	7.0	4	5.000	1.581
6	3.0	4.0	3.0	3.0	4	3.250	.433
7	3.0	6.0	3.0	7.0	4	4.750	1.785
8	3.0	3.0	3.0	3.0	4	3.000	0
9	8.0	8.0	5.0	8.0	4	7.250	1.299
10	---	7.5	8.0	6.0	3	7.167	0.850
11	6.0	5.0	4.0	7.0	4	5.500	1.118
12	4.0	3.5	4.0	5.0	4	4.125	.545
13	3.0	5.0	4.0	5.0	4	4.250	.829
14	3.0	4.0	4.0	4.0	4	3.750	.433
15	5.0	---	4.0	4.0	3	4.333	.471
16	4.0	---	4.0	4.0	3	4.000	0
17	7.0	7.5	5.0	10.0	4	7.375	1.781
18	7.0	4.0	4.5	7.0	4	5.625	1.386
19	5.0	8.0	5.0	7.0	4	6.250	1.299
20	5.0	3.0	4.5	5.0	4	4.375	.820
21	4.0	---	3.0	4.0	3	3.667	.471
22	3.0	---	3.0	4.0	3	3.333	.471
23	4.0	---	2.0	4.0	3	3.333	.943
24	4.0	---	5.0	4.0	3	4.333	.471
25	6.0	8.0	4.0	5.0	4	5.750	1.479
26	4.0	5.0	4.0	6.0	4	4.750	.829
27	3.0	8.0	4.0	10.0	4	6.250	2.861
28	3.0	4.0	3.0	3.0	4	3.250	.433
29	4.0	7.0	4.0	4.0	4	4.750	1.299
30	3.0	---	4.0	3.0	3	3.333	.471
31	3.0	---	3.0	4.0	3	3.333	.471
32	3.0	---	9.0	4.0	3	5.333	2.625
33	7.0	9.0	4.0	5.0	4	6.250	1.920
34	3.0	7.0	2.0	4.0	4	4.000	1.871
37	3.0	---	3.0	4.0	3	3.333	.471
38	3.0	3.0	2.0	5.0	4	3.250	1.090
39	3.0	---	3.0	4.0	3	3.333	.471
40	5.0	---	9.0	3.0	3	5.667	2.494

TABLE F-1.- Concluded

Test configuration	p1	p2	p3	HQR p4	n	$\bar{x}$	sd
51	---	---	3.0	5.0	2	4.000	1.000
52	---	---	---	4.0	1	4.000	---
53	---	---	4.0	---	1	4.000	---
54	---	---	---	5.0	1	5 000	---
55	6.0	---	---	6.0	2	6.000	0
57	---	---	8.0	6.0	2	7.000	1.000
58	---	---	---	5.0	1	5.000	---

TABLE 2.- PILOT RATINGS FOR DECELERATION FLIGHT TASK

Test configuration	p1	p2	p3*	HQR p4	n	$\bar{x}$	sd
3	6.0	4.0	4.0	5.0	3	5.000	1.410
4	3.0	4.0	3.0	3.0	3	3.300	.818
5	3.0	4.0	3.0	7.0	3	4.600	2.500
6	3.0	3.0	3.0	4.0	3	3.300	.818
7	3.5	4.0	3.0	5.0	3	4.200	1.170
8	4.0	4.0	4.0	4.0	3	4.000	0
9	6.0	7.0	4.0	7.0	3	6.660	.680
10	---	4.0	6.0	5.0	2	4.500	.707
11	5.0	4.0	3.0	5.0	3	4.660	.824
12	3.0	3.0	5.0	4.0	3	3.300	.818
13	4.0	4.0	3.0	4.0	3	4.000	0
14	3.0	3.0	4.0	4.0	3	3.300	.818
15	4.0	---	3.0	4.0	2	4.000	0
16	4.0	---	3.0	3.0	2	3.500	.707
17	5.0	4.5	4.0	7.0	3	5.500	1.870
18	6.0	5.0	3.0	7.0	3	6.000	2.240
19	6.0	7.0	5.0	7.0	3	6.600	.680
20	3.0	4.5	6.0	3.0	3	3.500	1.220
21	4.0	---	3.0	3.0	2	3.500	.707
22	4.0	---	3.0	3.0	2	3.500	.707
23	5.0	---	3.0	4.0	2	4.500	.707
24	4.0	---	4.0	3.0	2	3.500	.707
25	4.0	4.0	3.0	4.0	3	4.000	0
26	3.0	5.0	3.0	3.0	3	3.600	1 630
27	3.0	4.0	3.0	7.0	3	4.600	2.940
28	4.0	4.0	3.0	2.0	3	3.300	1.630
29	4.0	4.0	3.0	3.0	3	3.600	.820
30	3.0	---	3.0	3.0	2	3.000	0
31	3.0	---	3.0	4.0	2	3.500	.707
32	4.0	---	2.0	3.0	2	3.500	.707
33	6.0	4.0	4.0	4.0	3	4.600	1.630
34	4.0	4.0	2.0	4.0	3	4.000	0
37	4.0	---	4.0	3.0	2	3.500	.707

TABLE F-2.- Concluded

Test configuration	p1	p2	p3*	HQR p4	n	$\bar{x}$	sd
38	2.0	3.0	2.0	4.0	3	3.000	1.410
39	3.0	---	3.0	3.0	2	3.000	0
40	4.0	---	3.0	3.0	2	3.500	.707
51	---	---	3.0	4.0	1	4.000	0
52	---	---	---	3.0	1	3.000	---
53	---	---	4.0	---	0	0	0
54	---	---	---	4.0	1	4.000	---
55	5.0	---	---	5.0	2	5.000	0
57	---	---	5.0	5.0	1	5.000	0
58	---	---	---	5.0	1	5.000	---

*Ratings were rejected due to low correlation.

TABLE F-3.- PILOT RATINGS FOR LOW HOVER TURN FLIGHT TASK

Test configuration	p1	p2	p3	HQR p4	n	$\bar{x}$	sd
3	5.0	7.0	5.0	6.0	4	5.750	0.829
4	3.0	3.0	3.0	3.0	4	3.000	0
5	4.0	4.0	3.0	7.0	4	4.500	1.500
6	4.0	4.0	4.0	3.0	4	3.750	.433
7	4.0	4.0	3.0	6.0	4	4.250	1.090
8	4.0	3.0	3.0	3.0	4	3.250	.433
9	7.0	7.0	5.5	8.0	4	6.875	.893
10	---	3.0	6.0	6.0	3	5.000	1.414
11	6.0	3.0	4.0	5.0	4	4.500	1.118
12	4.0	3.0	4.0	7.0	4	4.500	1.500
13	5.0	3.0	3.0	7.0	4	4.500	1.658
14	4.0	4.0	4.0	4.0	4	4.000	0
15	5.0	---	4.0	5.0	3	4.667	.471
16	4.0	---	3.0	4.0	3	3.667	.471
17	6.0	3.0	5.0	6.0	4	5.000	1.225
18	7.0	6.0	3.0	3.0	4	4.750	1.785
19	4.0	5.0	5.0	7.0	4	5.250	1.090
20	3.0	3.0	4.0	3.0	4	3.250	.433
21	4.0	---	3.0	4.0	3	3.667	.471
22	4.0	---	3.0	4.0	3	3.667	.471
23	5.0	---	3.0	5.0	3	4.333	.943
24	4.0	---	3.0	4.0	3	3.667	.471
25	5.0	5.0	4.0	5.0	4	4.750	.433
26	3.0	2.5	4.0	3.0	4	3.125	.545
27	4.0	4.0	3.0	7.0	4	4.500	1.500
28	4.0	3.0	3.0	3.0	4	3.250	.433
29	5.0	4.0	4.0	4.0	4	4.250	.433
30	2.0	---	3.0	4.0	3	3.000	.816

TABLE F-3.- Concluded

Test configuration	p1	p2	p3	HQR p4	n	$\bar{x}$	sd
31	4.0	---	3.0	4.0	3	3.667	.471
32	4.0	---	3.0	3.0	3	3.333	.471
33	4.0	6.0	4.0	6.0	4	5.000	1.000
34	4.0	3.0	2.0	3.0	4	3.000	.707
35	4.0	---	3.0	4.0	3	3.667	.471
37	3.0	4.0	2.0	4.0	4	3.250	.829
39	4.0	---	3.0	4.0	3	3.667	.471
40	5.0	---	3.0	4.0	3	4.000	.816
51	---	---	3.0	5.0	2	4.000	1.000
52	---	---	---	5.0	1	5.000	---
53	---	---	4.0	---	1	4.000	---
54	---	---	---	5.0	1	5.000	---
55	6.0	---	---	5.0	2	5.500	.500
57	---	---	9.0	5.0	2	7.000	2.000
58	---	---	---	5.0	1	5.000	---

TABLE F-4.- PILOT RATINGS FOR HIGH HOVER TURN FLIGHT TASK

Test configuration	p1	p2	p3	HQR p4	n	$\bar{x}$	sd
3	5.0	7.0	5.0	6.0	4	5.750	0.829
4	3.0	3.0	3.0	3.0	4	3.000	0
5	4.0	3.0	3.0	7.0	4	4.250	1.639
6	4.0	4.0	4.0	3.0	4	3.750	.433
7	3.5	4.0	4.0	6.0	4	4.375	.960
8	4.0	3.0	3.0	3.0	4	3.250	.433
9	7.0	7.0	5.5	7.0	4	6.625	.650
10	---	3.0	6.0	5.0	3	4.667	1.247
11	6.0	3.0	4.0	7.0	4	5.000	1.581
12	4.0	3.0	3.5	7.0	4	4.375	1.556
13	5.0	3.0	3.0	6.0	4	4.250	1.299
14	4.0	4.0	4.0	4.0	4	4.000	0
15	5.0	---	4.0	5.0	3	4.667	.471
16	4.0	---	3.0	4.0	3	3.667	.471
17	6.0	3.0	5.0	6.0	4	5.000	1.225
18	7.0	6.0	4.0	3.0	4	5.000	1.581
19	4.0	4.0	5.0	7.0	4	5.000	1.225
20	3.0	3.0	4.0	3.0	4	3.250	.433
21	4.0	---	3.0	5.0	3	4.000	.816
22	4.0	---	3.0	4.0	3	3.667	.471
23	5.0	---	3.0	5.0	3	4.333	.943
24	4.0	---	3.0	4.0	3	3.667	.471
25	5.0	5.0	4.0	5.0	4	4.750	.433
26	3.0	2.5	3.0	3.0	4	2.875	.217

TABLE F-4.- Concluded

Test configuration	p1	p2	p3	HQR p4	n	x̄	sd
27	4.0	4.0	3.0	7.0	4	4.500	1.500
28	4.0	3.0	3.5	3.0	4	3.375	.415
29	5.0	4.0	4.0	4.0	4	4.250	.433
30	2.0	---	3.0	4.0	3	3.000	.816
31	4.0	---	3.0	5.0	3	4.000	.816
32	4.0	---	3.0	4.0	3	3.667	.471
33	4.0	6.0	4.0	6.0	4	5.000	1.000
34	4.0	3.0	3.0	3.0	4	3.250	.433
37	4.0	---	3.0	4.0	3	3.667	.471
38	3.0	4.0	2.0	4.0	4	3.250	.829
39	4.0	---	3.0	4.0	3	3.667	.471
40	5.0	---	3.0	4.0	3	4.000	.816
51	---	---	3.0	5.0	2	4.000	1.000
52	---	---	---	5.0	1	5.000	---
53	---	---	4.0	---	1	4.000	---
54	---	---	---	5.0	1	5.000	---
55	6.0	---	---	6.0	2	6.000	0
57	---	---	6.0	6.0	2	6.500	.500
58	---	---	---	5.0	1	5.000	---

TABLE F-5.- PILOT RATINGS FOR TARGET ACQUISITION AND TRACKING FLIGHT TASK

Test configuration	p1	p2*	p3	HQR p4	n	x̄	sd
3	7.0	7.0	99.0	7.0	3	7.000	0
4	4.0	99.0	3.5	4.0	3	3.833	.236
5	5.0	99.0	4.0	7.0	3	5.333	1.247
6	4.0	5.0	99.0	5.0	2	4.500	.707
7	4.0	5.0	4.0	6.0	3	4.600	1.630
8	5.0	6.0	4.0	99.0	2	4.500	.707
9	4.0	7.0	6.0	7.0	3	5.660	2.160
10	---	5.0	6.0	99.0	1	6.000	1.000
11	99.0	99.0	5.0	7.0	2	6.000	1.000
12	5.0	99.0	4.0	5.0	3	4.667	.471
13	4.0	6.0	4.0	5.0	3	4.330	.812
14	99.0	5.0	5.5	4.0	3	4.833	.624
15	4.0	---	4.0	4.0	3	4.000	0
16	4.0	---	3.0	6.0	3	4.333	1.247
17	7.0	6.0	5.0	99.0	3	6.000	.816
18	99.0	99.0	4.0	4.0	2	4.000	0
19	99.0	99.0	4.0	5.0	2	4.500	.500
20	6.0	7.0	5.0	4.0	3	5.000	1.410
21	99.0	---	4.0	4.0	2	4.000	0
22	99.0	---	4.0	5.0	2	4.500	.500

TABLE F-5.- Concluded

Test configuration	p1	p2*	p3	HQR p4	n	$\bar{x}$	sd
23	6.0	---	3.0	5.0	3	4.667	1.247
24	5.0	---	4.0	6.0	3	5.000	.816
25	6.0	7.0	4.5	4.0	3	4.800	1.470
26	5.0	5.0	5.0	7.0	3	6.300	1.960
27	5.0	7.0	3.0	5.0	3	4.300	1.630
28	5.0	7.0	3.0	3.0	3	3.400	2.540
29	4.0	4.0	99.0	4.0	3	4.000	0
30	4.0	---	4.0	3.0	3	3.667	.471
31	4.0	---	99.0	7.0	2	5.500	1.500
32	5.0	---	99.0	99.0	1	5.000	0
33	99.0	99.0	4.0	5.0	2	4.500	.500
34	4.0	7.0	2.0	3.0	3	3.000	1.410
37	99.0	---	3.5	99.0	1	3.500	0
38	4.0	7.0	3.0	4.0	3	3.500	.860
39	99.0	---	3.0	5.0	2	4.000	1.000
40	99.0	---	99.0	4.0	1	4.000	0
51	---	---	3.0	4.0	2	3.500	.500
52	---	---	---	4.0	1	4.000	---
53	---	---	4.0	---	1	4.000	---
54	---	---	---	6.0	1	6.000	---
55	5.0	---	---	6.0	2	5.500	.500
57	---	---	99.0	5.0	1	5.000	0
58	---	---	---	4.0	1	4.000	---

*Ratings rejected due to negligible correlation.

TABLE F-6.-PILOT RATINGS CORRELATION MATRIX FOR TASK 1

$$\hat{\rho} = \hat{c}_{XY} = \frac{\sum_{i=1}^{n} (X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i-\bar{X})^2 \sum_{i=1}^{n} (Y_i-\bar{Y})^2}} .$$

*		p1 3	p2 4	p3 5	p4 6	pavg 7	p1avg 8	p2avg 9	p3avg 10	p4avg 11
p1	3	1.0000								
p2	4	0.4274	1.0000							
p3	5	0.6422	0.2992	1.0000						
p4	6	0.4355	0.5512	0.5673	1.0000					
pavg	7	0.7654	0.7840	0.7137	0.8450	1.0000				
p1avg	8	0.5656	0.8271	0.6480	0.9020	0.9636	1.0000			
p2avg	9	0.8139	0.5520	0.8087	0.8589	0.9504	0.8799	1.0000		
p3avg	10	0.7413	0.8254	0.6173	0.8445	0.9916	0.9629	0.9184	1.0000	
p4avg	11	0.8506	0.8097	0.6988	0.6352	0.9498	0.8639	0.8700	0.9380	1.0000

TABLE F-7.- PILOT RATINGS CORRELATION MATRIX FOR TASK 2

		p1 3	p2 4	p3 5	p4 6	pavg 7	p1avg 8	p2avg 9	p3avg 10	p4avg 11
p1	3	1.0000								
p2	4	0.5900	1.0000							
p3	5	0.1330	0.2366	1.0000						
p4	6	0.4549	0.4890	0.0288	1.0000					
pavg	7	0.7832	0.8063	0.4022	0.7865	1.0000				
p1avg	8	0.5673	0.7905	0.4701	0.8279	0.9564	1.0000			
p2avg	9	0.7781	0.6473	0.4257	0.8218	0.9728	0.9227	1.0000		
p3avg	10	0.8078	0.8026	0.1433	0.8418	0.9637	0.8968	0.9275	1.0000	
p4avg	11	0.8206	0.8308	0.5597	0.4574	0.9089	0.8181	0.8459	0.8194	1.0000

*p1 – pilot 1; p2 – pilot 2; p3 – pilot 3; p4 – pilot 4; pavg – averaged rating; p1avg – av rating w/o p1; p2avg – av rating w/o p2; p3avg – av rating w/o p3; p4avg – av rating w/o p4

TABLE F-8.- PILOT RATINGS CORRELATION MATRIX FOR TASK 3

		p1 3	p2 4	p3 5	p4 6	pavg 7	p1avg 8	p2avg 9	p3avg 1Ø	p4avg 11
p1	3	1.ØØØØ								
p2	4	Ø.5141	1.ØØØØ							
p3	5	Ø.3431	Ø.4781	1.ØØØØ						
p4	6	Ø.33Ø2	Ø.3935	Ø.4179	1.ØØØØ					
pavg	7	Ø.7Ø35	Ø.7912	Ø.685Ø	Ø.7874	1.ØØØØ				
p1avg	8	Ø.4991	Ø.78Ø2	Ø.7122	Ø.8417	Ø.967Ø	1.ØØØØ			
p2avg	9	Ø.6939	Ø.5827	Ø.6861	Ø.862Ø	Ø.958Ø	Ø.9193	1.ØØØØ		
p3avg	1Ø	Ø.7269	Ø.7934	Ø.5346	Ø.8Ø48	Ø.9819	Ø.9365	Ø.933Ø	1.ØØØØ	
p4avg	11	Ø.79Ø1	Ø.8742	Ø.7Ø63	Ø.4717	Ø.9149	Ø.8322	Ø.8Ø61	Ø.8777	1.ØØØØ

TABLE F-9.- PILOT RATINGS CORRELATION MATRIX FOR TASK 4

		p1 3	p2 4	p3 5	p4 6	pavg 7	p1avg 8	p2avg 9	p3avg 1Ø	p4avg 11
p1	3	1.ØØØØ								
p2	4	Ø.5352	1.ØØØØ							
p3	5	Ø.5468	Ø.6369	1.ØØØØ						
p4	6	Ø.3243	Ø.2433	Ø.3641	1.ØØØØ					
pavg	7	Ø.7617	Ø.7693	Ø.7695	Ø.72ØØ	1.ØØØØ				
p1avg	8	Ø.5741	Ø.7642	Ø.76Ø1	Ø.7838	Ø.9678	1.ØØØØ			
p2avg	9	Ø.7492	Ø.5355	Ø.71Ø5	Ø.8346	Ø.9515	Ø.9114	1.ØØØØ		
p3avg	1Ø	Ø.7622	Ø.7497	Ø.6638	Ø.7568	Ø.9884	Ø.953Ø	Ø.9457	1.ØØØØ	
p4avg	11	Ø.8266	Ø.8868	Ø.8126	Ø.3533	Ø.9Ø36	Ø.82Ø8	Ø.7675	Ø.8653	1.ØØØØ

TABLE F-10.- PILOT RATINGS CORRELATION MATRIX FOR TASK 5

		p1 3	p2 4	p3 5	p4 6	pavg 7	p1avg 8	p2avg 9	p3avg 1Ø	p4avg 11
p1	3	1.ØØØØ	Ø.3228	Ø.3361	Ø.1269	Ø.72Ø2	Ø.4637	Ø.6338	Ø.6597	Ø.8168
p2	4	Ø.3228	1.ØØØØ	-Ø.442Ø	-Ø.255Ø	Ø.1769	Ø.Ø84Ø	-Ø.15Ø4	Ø.2879	Ø.4882
p3	5	Ø.3361	-Ø.442Ø	1.ØØØØ	Ø.5353	Ø.721Ø	Ø.8373	Ø.893Ø	Ø.3662	Ø.5398
p4	6	Ø.1269	-Ø.255Ø	Ø.5353	1.ØØØØ	Ø.7137	Ø.7861	Ø.8Ø94	Ø.6694	Ø.269Ø
pavg	7	Ø.72Ø2	Ø.1769	Ø.721Ø	Ø.7137	1.ØØØØ	Ø.9474	Ø.9419	Ø.8851	Ø.8511
p1avg	8	Ø.4637	Ø.Ø84Ø	Ø.8373	Ø.7861	Ø.9474	1.ØØØØ	Ø.9261	Ø.8296	Ø.7792
p2avg	9	Ø.6338	-Ø.15Ø4	Ø.893Ø	Ø.8Ø94	Ø.9419	Ø.9261	1.ØØØØ	Ø.589Ø	Ø.7683
p3avg	1Ø	Ø.6597	Ø.2879	Ø.3662	Ø.6694	Ø.8851	Ø.8296	Ø.589Ø	1.ØØØØ	Ø.57Ø6
p4avg	11	Ø.8168	Ø.4882	Ø.5398	Ø.269Ø	Ø.8511	Ø.7792	Ø.7683	Ø.57Ø6	1.ØØØØ

APPENDIX G

PILOT COMMENT DATA

Tables G-1 through G-5 list individual pilot comment data for each configuration flown while conducting the five designated tasks.

TABLE G-1.- PILOT COMMENTS ON TASK 1 (NOE FLIGHT)

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/17/84	6	No	3	26	4	I find that while the breakout is adequate, the force gradient could be a bit higher. As far as the directional access, the commanded position was there. It became immediately apparent that the damping was decreased somewhat and that there was a tendency to overshoot the desired heading.
1/17/84	7	Yes	3	3	5	The damping and control sensitivity were markedly decreased. One, by the frequency of directional motions required and in magnitude of motions in order to obtain the desired heading. In the turn there was tendency for reverse yaw, a substantial amount of pedal and a tendency to overshoot.
1/17/84	8	Yes	3	11	4	The damping appeared to be adequate, but the decrease in control sensitivity required the tendency to overshoot. The desired yaw rate could easily be commanded. The aircraft did not want to seem to turn as rapidly as I had commanded it to.
1/17/84	1	No	1	8	3	Very responsive, would prefer increased friction on the collective.
1/17/84	2	Yes	1	7	3	Increased friction on collective is a benefit.
1/17/84	3	No	1	18	7	Controllability in question. Lack of dampening exists in the yaw axis.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu-lence	Pilot	A/C config-uration	PR	Comments
1/17/84	9	Yes	3	27	4	Tendency to overcontrol the directional axis. The damping seemed to be adequate as the frequency of the pedal inputs was not that high; however, there was a tendency to overshoot on the desired heading.
1/17/84	10	No	3	34	2	Acute angle and reflex angle turns were exceptional. Excellent control and good ability to achieve the desired rate of turn or rate of yaw.
1/17/84	11	No	3	6	3	The additional control system damping was adequate and satisfactory; however, relative sensitivity was decreased. This decrease did not affect control, but it did increase the magnitude of pedal displacements in order to obtain the desired yaw rate or a skid through the turn. The turns were accomplished easily.
1/17/84	12	Yes	3	9	5	Apparent damping was substantially decreased with an apparent increase in sensitivity. Considerable difficulty in maintaining the desired heading down the NOE course within 5° and with some bicycling on the pedals.
1/17/84	13	Yes	3	13	4	Heading control was not a problem. It seemed like the aircraft was overall more sluggish, higher damping and a decrease in control sensitivity. It wasn't reacting as quick as I would have desired.
1/17/84	14	Yes	3	7	3	Maintaining desired heading was not a problem. The damping appeared adequate, the sensitivity perhaps was just higher than desired. Could be coupled with shorter than necessary time constant.
1/17/84	15	NO	1	28	3	Very sensitive in the yaw axis.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/17/84	16	Yes	1	33	7	It appeared that the pedals had no control or did not tend to streamline. The aircraft did not tend to streamline with the aircraft in forward flight. Yaw damping was inappropriate. High pilot workload required to maintain the aircraft as far as yaw control is concerned. Very poor scan system.
1/17/84	17	No	1	4	5	Pretty fair all in all. Good collective response. No change in pitch and roll over the previous configurations nor in collective. In going straight and narrow there were no problems; in clearing the berm, however, the heading does appear to want to drift right and left, depending upon the application or decrease of torque, requiring increased pilot workload.
1/18/84	1	No	3	10	8	Heading control is difficult. There are the desired normal frequency of pedal motion bicycling back and forth on the pedals, indicative of a low damping. There also appears to be relative low sensitivity. In straight runs control is no problem, in the turns it becomes one.
1/18/84	2	Yes	3	33	4	Increase in damping appeared to be marginal to adequate. Control sensitivity was low enough in requiring some of the large pedal excursions to establish the desired heading and desired rate, caused a tendency to lag--not necessarily overshoot but lag in trying to orient the helicopter.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	3	No	3	20	4.5	Sensitivity seemed higher. The damping was not sufficient for the control sensitivity, consequently there is a tendency to over control, evidenced by the frequency of back and forth of bicycling pedal motions. Performance on the straight runs was no problem. Control on turns was, however, at the desired speed.
1/18/84	4	Yes	3	19	5	Tendency to overcontrol. High frequency of back and forth pedal motions indicative of low damping. The sensitivity was not particularly high either. There was a large magnitude of pedal displacements, significant difficulty in maintaining the desired heading during the NOE run. Control not a problem. I had to slow down to obtain desired performance.
1/18/84	5	Yes	3	17	5	Damping was unsatisfactory. Sensitivity did appear to be increased and small magnitude pedal displacements would generate high yaw rates. Speed had to be slowed to 30-35 knots in order to negotiate the turns.
1/18/84	6	No	3	18	4.5	Damping appeared to be generally adequate. There was not a necessity of high frequency pilot inputs;, sensitivity appeared to have decreased.
1/18/84	7	No	3	14	4	Very highly damped. Very,very insensitive in the directional axis.
1/18/84	8	No	3	20	3	Good harmony between damping and sensitivity. Task could be accomplished within the desired performance criteria.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/16/84	1	No	1	34	3	Minimum compensation required. Collective very sensitive, very nice for controlling over berm and also going down the other side. A little trouble with the lower torque of the aircraft. Very sensitive yaw inputs. Small minor roll inputs cause the turn slip indicator to go outside of the trim conditions.
1/16/84	2	Yes	1	13	3	Controllability was no problem. Minimum compensation was required.
1/18/84	1	Yes	1	5	4	Compensation was required in the pitch and roll and I still feel the sensitivity in the pitch and roll axis is too little.
1/18/84	2	No	1	20	5	Considerable compensation primarily in the yaw axis compared to other configurations.
1/18/84	3	Yes	1	3	5	Considerable compensation in the yaw axis, very high sensitivity in the pedals.
1/18/84	4	Yes	1	27	3	Minimum compensation required maneuvering down the course. High gains in yaw axis make some compensation necessary.
1/1[illegible]/84	5	Yes	1	17	7	Performance obtainable, but only with maximum pilot compensation. Large yaw excursions and extensive compensation in the yaw axis to maintain any heading whatsoever.
1/18/84	6	Yes	1	11	6	Extensive compensation required to maintain any kind of directional control throughout the maneuver.
1/18/84	10	No	3	12	4	Initial tendency to overcontrol in the yaw axis with the aircraft overcompensating. Control sensitivity very high. Did not have a noticeable weathercock stability or side force characteristics with forward airspeeds.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	11	Yes	3	25	4	Tendency to overcontrol slightly (1 or 2°). Slightly decreased in sensitivity.
1/18/84	12	Yes	3	5	3	Forward speed directional stability seemed adequate with airspeed. No problem maintaining the desired heading in the straight runs and the turns were relatively easier than the other configurations.
1/18/84	13	No	3	4	3	Damping appeared to be somewhat lower, and control sensitivity unchanged from previous runs, and so consequently the aircraft had some apparent quickness. Maintained desired heading.
1/18/84	14	No	3	40	9	Highly damped, totally insensitive control system. Turning the aircraft was difficult. You had to roll the aircraft and once you got it over in a reasonable high bank angle, then you had to pitch the aircraft through the turn, causing pedal deflection.
1/18/84	15	No	3	32	9	Aircraft does not want to turn in forward flight. Lack of control in the turns.
1/19/84	1	No	3	24	5	Seemed underdamped in forward flight. Tendency to overcontrol in pedal motions.
1/19/84	2	Yes	3	31	3	Adequate weathercock stability. Adequate side forces were generated for commanded side slip angles. Damping and sensitivity appeared to be well matched and the forward flight regime could negotiate the large angle turn without any major difficulty.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	3	Yes	3	29	4	Damping appeared to be adequate in relative comparison. Control sensitivity was not significantly lower than what I'd want it to be. It required large pedal excursions in order to generate the correct yaw. However, that was ameliorated because of the rather high damping, so consequently there was not a tendency to overcontrol.
1/19/84	4	Yes	3	15	4	Aircraft did not seem to have the full flight weathercock stability and I had to resort to more pedal inputs to coordinate the turns.
1/19/84	5	Yes	3	23	2	Good forward flight stability. Good weathercock stability. Could easily fly through the turns.
1/19/84	6	Yes	3	39	3	Could fly through the turns without problems. Major collective inputs to go up and over the berms did not induce large yaw excursions, and was able to reasonably fly through at the generally targeted airspeed.
1/19/84	7	No	3	30	4	Good flight track. Directional stability could generate adequate side forces. It was not quite as well damped in forward flight as the last two. No major increase in workload.
1/19/84	8	No	3	22	3	Good forward flight stability. No appreciative pedal displacements. Tendency to make me overconfident.
1/19/84	9	Yes	3	16	4	It did quite well through the turns. Adequate damping and control sensitivity but required a bit more work.
1/19/84	10	Yes	3	53	4	Very lightly damped. Slight tendency to overcontrol.
1/19/84	11	Yes	3	57	8	Damping was virtually nonexistent. Adequate control in question.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	12	Yes	3	51	3	Able to generate adequate side forces with side slip. Able to fly through the turns with minimum pedal displacement.
1/19/84	2	No	2	12	3.5	Heading information up here on the HUD, especially the altitude information helps a good deal. I don't use the torque at all and the heading is relatively useless during the NOE. All I am using for the NOE portion is the right portion with the tape and altitude readout. The biggest problem I saw was the heading shift as a function of increasing and decreasing power going over the berm, so there was a slight tendency for the nose to shift right with increased power.
1/19/84	3	Yes	2	17	7.5	A lot more difficult to fly primarily due to the degraded yaw control. Aircraft nose was much more active in going left and right. In power applications and actually going over the first berm, it was almost uncontrollable due to a rather rapid application of power on my part. Difficult to have any precise tracking. However, jumping over the one berm, it was controllable.
[illegible]3/84	1	Yes	2	7	6	Biggest workload was trying to get the aircraft to make it around the turns without smacking into the sides. It took an awful lot of bank angle and a whole lot of pedal to get the aircraft coming around. 40 knots seemed to be far too fast to maneuver the aircraft with the bank and yaw characteristics.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/23/84	2	No	2	26	5	I liked the handling qualities of the aircraft better. It seemed easier to make the turns at 40 knots without smacking into the side. The aircraft seemed looser in yaw control and seemed much less stable or steady in a particular heading, so that it did require a little bit of pedal inputs all the time you were flying, but the turns in fact were easier. I had some trouble with altitude control and a little heading control problem.
1/23/84	3	Yes	2	13	5	Nothing much different other than I did lose the panel-mounted display. It seemed like it took an excessive amount of bank angle and pedal to stop the aircraft from sliding to the left.
1/23/84	4	No	2	34	7	Difficult coordinated turn. On the second turn I tried to come inside and look at the panel-mounted display and use the velocity vector to help me determine whether or not I was coordinated. The coordination scene is really poor. It seems like it is taking an excessive amount of bank angle and pedal input to get around the turn, continually wanting to slide.
1/23/84	5	No	2	28	4	I felt my ability to fly a predetermined path over the ground to keep the aircraft in the center line of the canyon was easier than it had been on previous runs. Bank angle on pedal displacements in the turn did not seem excessive. Airspeed control was good.
1/23/84	6	No	2	10	7.5	The predictability of the pedal requirements is very poor when the aircraft is banked. The aircraft was loose and wallowing around in yaw control. A slight pedal displacement caused a very large yaw displacement and I could not figure out what the steady state rate was.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/23/84	7	Yes	2	5	8	I had to slow down to 20-25 knots to negotiate the course. Any faster and I would have flown through the sides of the course.
1/23/84	8	Yes	2	19	8	In the right turn the aircraft dished out to the left and then yaw control became extremely uncoordinated. The nose kept turning to the right.
1/24/84	1	Yes	1	19	5	Considerable compensation required in the yaw axis, especially when negotiating the turns.
1/24/84	2	Yes	1	9	8	Large pedal inputs required to compensate for yaw drift once you put the pedal in (a fair amount), it feels like there's a delay and then a large rate occurs, so large inputs are required to maintain some kind of straight course.
1/24/84	3	Yes	1	25	6	Extensive compensation was required in maintaining directional control. This also affected maintaining a proper course through the NOE area.
1/24/84	4	No	1	12	4	No comments.
1/24/84	5	Yes	1	39	3	Minimal compensation required, minor yaw inputs required with collective application.
1/24/84	6	No	1	22	3	Very easy to fly down the course.
1/24/84	1	No	2	6	4	Aircraft had a tendency to dish out a bit in the turns, but I was able to keep it within what I considered acceptable limits while traversing the canyon area. Yaw excursions with collective increases and decreases were minimal.
1/24/84	2	No	2	8	3	Control seemed real smooth and the predictability was very good.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/24/84	3	No	2	4	4.5	Yaw axis seemed to be a bit undamped. I would like to have more positive control over it.
1/24 84	5	No	4	4	3.5	No particular problems.
1 [illegible] 84	6	Yes	4	18	7	Because of the poor heading response, I ended up doing "S" turns down the course.
1 [illegible] 84	7	No	4	12	5	The nose was twitchy and very sensitive. The nose kept wobbling back and forth as the aircraft went down the course.
1 2[illegible]	10	No	4	26	6	Overshot the turns and had to "S" turn down the course.
1/[illegible]	11	No	4	6	3	Slight overshoot in yaw axis during turns, but not nearly to the extent that I've seen before.
1 [illegible]4	12	No	4	20	5	Not much power to yaw coupling, but I did have to chase the heading after coming out of the turns.
1 4 84	13	Yes	4	13	5	The addition of the wind caused me to overcompensate in controlling the yaw axis.
1 [illegible]4 [illegible]4	14	Yes	4	27	10	Extremely sensitive in the yaw axis to the extent that I had to slow down in attempting the turns, even though I eventually lost control and crashed.
1/24/84	15	Yes	4	19	7	To maintain adequate control I had to slow down 10 knots.
1[illegible]/84	16	Yes	4	9	8	In this run, flying NOE was not the primary task, it was maintaining aircraft control.
1 25/84	2	Yes	2	14	4	Yaw and roll coordination into the turns was very good.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/25/84	3	Yes	2	9	8	The aircraft was fairly loose in yaw control, and it required quite a bit of activity on the pedals to try to keep the nose straight. It was so difficult to control in yaw that altitude and speed control deteriorated.
1/25/84	4	No	2	20	3	The turn coordination was really great.
1/25/84	5	Yes	2	27	8	The aircraft required a lot of pedal to establish a good turn. I had to slow down to 20 knots to make the turns.
1/25/84	6	Yes	2	33	9	It took excessive amounts of pedal and roll coordination just to get the aircraft to turn.
1/25/84	1	No	1	30	3	Very nice and easy to control in the yaw axis.
1/25/84	2	No	1	28	3	No problems.
1/25/84	3	Yes	1	21	4	You've got to be a little more active in the loop to keep the desired heading as you make collective changes.
1/25/84	1	Yes	4	11	7	The yaw to collective coupling was a problem. There seemed to be a longer than normal lag in the yaw response.
1/25/84	2	No	4	28	3	Minimal compensation, no obnoxious power to yaw coupling.
1/25/84	3	Yes	4	33	5	I had to slow down considerably to negotiate the course.
1/26/84	1	Yes	2	25	8	The yaw control during turn coordination was very poor. The aircraft was very loose in directional control.
1/26/84	2	Yes	2	11	5	Extensive pilot compensation was required primarily based on the difficulty in making the right turn.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/26/84	3	No	2	18	4	I was able to roll into and out of the turns without a lot of workload in trying to continually increase the bank angle and pedal inputs to keep the aircraft in the center. I did not like the yaw to collective coupling.
1/26/84	4	Yes	2	3	7	The aircraft was continually wallowing around. I was not able to make precise pedal inputs and get a desired result.
1/26/84	5	Yes	2	38	3	It required some pedal in the turns, but I was quickly able to recognize what I needed in the way of pedal input and immediately get it when I initiated the controls. It felt real comfortable.
1/26/84	6	Yes	2	29	7	You can keep the nose in what looks like a coordinated turn but the aircraft just doesn't want to turn.
1/26/84	1	Yes	1	29	4	I was very aggressive in this particular operation, more so than I've been in the past.
1/26/84	2	Yes	1	13	3	It is easy to compensate with the pedals for any yaw excursions that I experienced throughout the course.
1/26/84	3	No	1	40	5	The NOE course requires considerable pilot compensation in the yaw axis in making heading changes while making turns. It is easy to maintain heading while increasing or decreasing the collective.
1/26/84	4	Yes	1	23	4	Moderate pilot compensation was required to negotiate the turn properly. The sensitivity seems to be increased a bit.
1/26/84	5	No	1	32	3	Easy to negotiate the course. Collective applications required no pedal correlation.

TABLE G-1.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/26/84	6	Yes	1	15	5	Considerable compensation in the yaw axis in negotiating the turns. Also, collective to yaw coupling required increased pilot workload.
1/26/84	7	No	1	24	4	The sensitivity isn't very high, but you still need to be in the loop pretty tight to negotiate the course with any aggressiveness.
1/26/84	8	Yes	1	31	3	Collective to yaw correlation requiring no compensation in the yaw axis. It was easy to negotiate turns.
1/26/84	9	Yes	1	16	4	Heading control was very good. It was very easy to negotiate the turns.
1/26/84	10	Yes	1	55	6	Extensive pilot compensation required in yaw axis, especially in negotiating the turns.
1/26/84	1	Yes	4	39	4	I had to work with the pedals more than I liked. The yaw seemed like it wasn't as responsive as it should have been in negotiating.
1/26/84	2	No	4	30	3	Minimal compensation, no power to yaw feedback.
1/26/84	3	Yes	4	37	4	Moderate compensation to go through NOE course. No power to yaw correlation required.
1/26/84	4	No	4	24	4	I could detect a little bit of wallowing and lack of preciseness in the heading control.
1/26/84	5	Yes	4	21	4	Every time I would go over a berm and make a large power change, coming back down would require a lot of right pedal to keep the nose where I wanted it.
1/26/84	6	No	4	40	3	Minimal compensation required. I was able to keep my speed up fairly well.

TABLE G-1.- Concluded

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/26/84	7	No	4	22	4	The heading would wobble every time I would make a power change and it took reasonably large pedal applications to correct.
1/26/84	8	Yes	4	23	4	There was a lack of preciseness in heading control.
1/26/84	9	Yes	4	51	5	Considerable compensation due to power to yaw compensation and the apparent unpredictability of the pedals.
1/26/84	10	No	4	54	5	I had to overcompensate in yaw control to negotiate the course.
1/26/84	11	No	4	52	4	The first turn was easy the second turn was reasonable.
1/26/84	12	Yes	4	55	6	Very difficult to control.
1/26/84	13	No	4	58	5	Some power to yaw compensation required.

TABLE G-2.- PILOT COMMENTS ON TASK 2 (DECELERATION)

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/17/84	6	No	3	26	3	Heading control not a problem. Again, it's a matter of coordinating the collective.
1/17/84	7	Yes	3	3	4	It was evident that the normal directional control motions required in order to maintain the hover were increased.
1/17/84	8	Yes	3	11	3	The desired heading could be maintained.
1/17/84	1	No	1	8	4	Moderate compensation from the sensitivity of the controls increased power workload to stabilize the desired hover point. Tendency to PIO within the collective bounce with the high sensitivity set on them.
1/17/84	2	Yes	1	7	3.5	Takes a little more power workload to stabilize at the desired point. I think some of the compensation might have been on the collective.
1/17/84	3	No	1	18	6	Controllability becomes questionable.
1/17/84	9	Yes	3	27	3	No major problems in maintaining directional.
1/17/84	10	No	3	34	2	Directional control not a problem, the desired heading could easily be attained.
1/17/84	11	No	3	6	3	Decrease in sensitivity caused the heading to wander in the normal collective coupling, in that there was larger than perhaps desired, pedal displacement.
1/17/84	12	Yes	3	9	4	Oversensitivity in the pedals had a tendency to make me oscillate what I was trying to target for my desired heading.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/17/84	13	Yes	3	13	3	Aircraft had less of a tendency to wander in heading as the aircraft was decelerating.
1/17/84	14	Yes	3	7	3	Not difficult. I entered 10 to 12 knots slower than I have in the previous runs.
1/17/84	4	No	1	28	4	The sensitivity in the pitch is particularly noticeable. On that approach I got down to 3 ft prior to stopping the aircraft's forward motion and along with that some minor yaw excursions. High pilot workload.
1/17/84	5	Yes	1	33	6	High pilot workload. Collective response very good. Ability to maintain a desired altitude once established, excellent.
1/17/84	6	No	1	4	3	Very easy control.
1/18/84	1	No	3	10	6	Heading control is difficult because of the decrease in damping and apparent insensitivity to the controls.
1/18/84	2	Yes	3	33	4	No problems. Desired performance could be obtained. Perhaps larger than desired pedal excursions.
1/18/84	3	No	3	20	6	Significant difficulty in trying to maintain the desired heading performance. A median frequency bicycling motion back and forth in order to try and keep the nose generally the way we wanted it to go.
1/18/84	4	Yes	3	19	5	Low damping, low control sensitivity, bicycling back and forth on the pedals.
1/18/84	5	Yes	3	17	4	Easily accomplished, while compensating for the decrease in damping.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/18/84	6	No	3	18	3	Adequate damping even though it was low control sensitivity. The desired performance could be obtained without a problem.
1/18/84	7	No	3	14	4	Not particularly difficult.
1/18/84	8	No	3	20	3	No problem with desired performance.
1/16/84	1	No	1	34	4	The collective to yaw coupling inputs required by the pilot are considerable in that area, in that it requires moderate compensation by the pilot to maintain the heading. Very easy and safe to decelerate the aircraft with a nose-up attitude.
1/16/84	2	Yes	1	13	4	Moderate compensation. A very aggressive quick stop maneuver. I find that the controls are sensitive in pitch, roll, and yaw when trying to stabilize a desired altitude at a specific point.
1/18/84	1	Yes	1	5	3	Moderate compensations. Compensation was required in the pitch and roll and I still feel the sensitivity in the pitch and roll axis--it's a bit too much for that particular maneuver.
1/18/84	2	No	1	20	3	Minimal compensation. Easy to control the aircraft.
1/18/84	3	Yes	1	3	6	Very hard to stop the aircraft yaw and high sensitivity in the pedals. I ended up overshooting the point. I'm more concerned with the control of the aircraft requiring extensive pilot compensation just to slow the aircraft and attempt to maintain a heading.
1/18/84	4	Yes	1	27	3	Not much compensation required.
1/18/84	5	Yes	1	17	5	Extensive compensation required once slowing some of the airspeed, high power workload in yaw axis to obtain any kind of directional stability.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	6	Yes	1	11	5	Considerable pilot compensation required once the airspeed slows down. High power workload in the pedals to maintain directional control.
1/18/84	10	No	3	12	5	Significant overcontrol tendencies in maintaining the desired heading ±5°.
1/18/84	11	Yes	3	25	3	No problems.
1/18/84	12	Yes	3	5	3	No tendency to overcontrol with the nose altitude in maintaining the desired heading.
1/18/84	13	No	3	4	3	Damping appeared lower.
1/18/84	14	No	3	40	3	A piece of cake.
1/18 84	15	No	3	32	2	A piece of cake.
1/19/84	1	No	3	24	4	Not a substantial problem. There was not the apparent tendency to overcontrol.
1/19/84	2	Yes	3	31	3	No problems with heading control. No tendency to overcontrol.
1/19/84	3	Yes	3	29	3	Heading control not a problem. Large pedal excursions factor. Heavily damped decreased tendency to overcontrol or make it virtually nonexistent.
1/19/84	4	Yes	3	15	3	No significant problems in maintaining heading control and decelerating.
1/19/84	5	Yes	3	23	3	Slight tendency to overcontrol on my part, down when we got into the translational environment.
1/19/84	6	Yes	3	39	3	No tendency for the nose to wander.
1/19/84	7	No	3	30	3	No problems.
1/19/84	8	No	3	22	3	No real tendency for the nose to wander.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	9	Yes	3	16	3	Too fast. I started decelerating too late. Tendency to overshoot the area, not overshoot but, in the DECEL to have a higher than perhaps desired nose attitude. That did not adversely affect being able to hold the heading.
1/19/84	10	Yes	3	53	4	Really no problems. I had to go back and forth on the pedals to maintain the heading.
1/19/84	11	Yes	3	57	5	No particularly abrupt or rapid maneuver. Control is not in question but had to work at doing it.
1/19/84	12	Yes	3	51	3	No real major problems. I was able to keep heading under control.
1/19/84	2	No	2	12	3	Quite nice. The symbology helps a lot. Prefer head up display. Biggest task was getting the nose up high enough so as not to overshoot the desired points. It seemed like it takes a nose-up pitch attitude in order to anticipate and overshoot the desired point of stop.
1/19/84	3	Yes	2	17	4.5	Once I got the aircraft settled down through the first turn and all, the second turn went much better. However, I slowed the airspeed from 40 to 20 knots, I think, which may have been the factor for the improvement. Overall deceleration was acceptable. Heading control was not much of a problem although it was a bit looser in the deceleration in the previous run.
1/23/84	1	Yes	2	7	4	Task would be a lot easier if the velocity vector was on HUD rather than PMD where you had to come inside to assist in getting a rate of deceleration. You could get desired performance, with moderate compensation.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/23/84	2	No	2	26	5	Went to pot, mostly because of cross-check rather than aircraft performance. Task would be simpler if you could gauge your deceleration. Adequate performance was obtainable.
1/23/84	3	Yes	2	13	4	Desired performance required just moderate compensation.
1/23/84	4	No	2	34	4	I never did switch to the hover mode, but guess it doesn't matter because it didn't have the symbology. Nothing of any significance. Desired performance and just moderate compensation.
1/23/84	5	No	2	28	4	The heading control was fine.
1/23/84	6	No	2	10	4	Heading control didn't seem to be much of a problem.
1/23/84	7	Yes	2	5	4	Nothing significant to point out there.
1/23/84	8	Yes	2	19	7	Heading control was very poor during the transition from flight to hover.
1/24/84	1	Yes	1	19	6	Extensive compensation required in controlling yaw axis.
1/24/84	2	Yes	1	9	6	Large pedal inputs required to maintain some kind of a straight course.
1/24/84	3	Yes	1	25	4	Moderate compensation required.
1/24/84	4	No	1	12	3	Yaw axis controllability worked out very well.
1/24/84	5	Yes	1	39	3	It was very easy to maintain heading during the deceleration.
1/24/84	6	No	1	22	4	Very easy to execute the quick stop. Some compensation was required for yaw excursions due to collective changes.
1/24/84	1	No	2	6	3	The deceleration was simple and easy. No problems with yaw control.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/24/84	2	No	2	8	4	No problems encountered.
1/24/84	3	No	2	4	4	Having a slight problem with visual cues.
1/24/84	5	No	4	4	3	Not a lot of compensation required.
1/24/84	6	Yes	4	18	7	Large power changes caused large excursions in heading.
1/24/84	7	No	4	12	4	I kept putting in lots of pedal in chasing the yaw movement of the nose.
1/24/84	10	No	4	26	3	No particular comments. Performed normal deceleration.
1/24/84	11	No	4	6	4	No large problems due to yaw. There was a slight amount of collective to yaw coupling which caused a change in heading of 8°.
1/24/84	12	No	4	20	3	No problems in maintaining aircraft heading.
1/24/84	13	Yes	4	13	4	The addition of the wind did not cause much of a problem.
1/24/84	14	Yes	4	27	7	I overcontrolled the yaw axis a lot. The workload was so high that I forgot to go from transition mode to hover mode on the HUD.
1/24/84	15	Yes	4	19	7	Overcontrolled the yaw axis during the deceleration.
1/24/84	16	Yes	4	9	7	Because I was trying to control altitude with large collective movements, heading control was off a considerable amount.
1/24/84	2	No	2	14	3	Deceleration to a hover was comfortable and easy to do.
1/25/84	3	Yes	2	9	4	It was a fairly steady deceleration without much problem in yaw axis.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/25/84	4	No	2	20	4.5	No problems with yaw control during deceleration.
1/25/84	5	Yes	2	27	4	The deceleration went fairly smoothly.
1/25/84	6	Yes	2	33	4	The aircraft was fairly stable in yaw during the deceleration.
1/25/84	1	No	1	30	3	Easily controllable in yaw axis.
1/25/84	2	No	1	28	2	Pilot compensation was not a factor, especially in the yaw axis.
1/25/84	3	Yes	1	21	4	I have to make a fair amount of pedal inputs to maintain the heading.
1/25/84	1	Yes	4	11	5	No particular problems.
1/25/84	2	No	4	28	2	There wasn't a lot to do in the yaw axis since there was minimal yaw to collective coupling.
1/25/84	3	Yes	4	33	4	There was no substantial collective to yaw coupling and any change in heading was pilot induced.
1/26/84	1	Yes	2	25	4	No significant problems, directional control was fairly easy.
1/26/84	2	Yes	2	11	4	No problems with yaw control.
1/26/84	3	No	2	18	5.5	The yaw to collective coupling was fairly noticeable on the start of the deceleration. It was difficult to modulate the nose movement with pedal inputs because the pedals were so sensitive.
1/26/84	4	Yes	2	3	4	No problems with yaw control during initial stages of deceleration, but the aircraft seemed to want to wander around in heading toward the deceleration termination.
1/26/84	5	Yes	2	38	3	Heading was no problem The aircraft responded nicely.

TABLE G-2.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/26/84	6	Yes	2	29	4	I was able to control the yaw axis very well.
1/26/84	1	Yes	1	29	4	I flew this maneuver very aggressively.
1/26/84	2	Yes	1	13	4	It was relatively easy to maintain a desired heading during the deceleration; however, there was moderate compensation in correlating the yaw to collective coupling.
1/26/84	3	No	1	40	4	It didn't require much compensation to maintain a desired heading while applying the collective, but if an input were made it required a fair amount of compensation to control the heading.
1/26/84	4	Yes	1	23	5	I had to stay in the yaw loop to maintain the desired heading.
1/26/84	5	Yes	1	32	4	I was able to stabilize close to the desired heading with a moderate amount of compensation.
1/26/84	6	Yes	1	15	4	It required moderate pilot compensation to maintain the desired direction. I was finding also that the yaw has some effects in coupling into the roll axis.
1/26/84	7	No	1	24	4	Moderate compensation, but I was able to stabilize on approximately the desired heading.
1/26/84	8	Yes	1	31	3	Very aggressively flown. Heading control worked out beautifully.
1/26/84	9	Yes	1	15	4	There is not much in terms of pilot workload in yaw and collective.
1/26/84	10	Yes	1	55	5	High pilot workload in the quick stop, and I also attacked the maneuver with considerably less aggressiveness than I've done before.
1/26/84	1	Yes	4	39	3	No pedal to power compensation required by the pilot.

TABLE G-2.- Concluded

Date	Run no.	Wind/ turbu-lence	Pilot	A/C config-uration	PR	Comments
1/26/84	2	No	4	30	3	No particular problems. No pilot workload in yaw to keep it on heading.
1/26/84	3	Yes	4	37	3	Not much compensation required.
1/26/84	4	No	4	24	3	I am able to hold the nose generally in the right direction and roll out on north at the end of the deceleration.
1/26/84	5	Yes	4	21	3	Not a lot of compensation required.
1/26/84	6	No	4	40	3	No apparent yaw to power coupling problems that I was required to compensate for.
1/26/84	7	No	4	22	3	There wasn't much compensation required during the deceleration.
1/26/84	8	Yes	4	23	4	The yaw control workload was considerably higher than what I thought it should be.
1/26/84	9	Yes	4	51	4	Moderate compensation required to maintain the heading.
1/26/84	10	No	4	54	5	It wasn't high on workload. I only wandered off inheading 5°-10°.
1/26/84	11	No	4	52	3	Minimal drift in heading control
1/26/84	12	Yes	4	55	5	I had to really concentrate in making only very small pedal movements.
1/26/84	13	No	4	58	5	Yaw to power compensation required.

TABLE G-3.- PILOT COMMENTS ON TASK 3 (LOW HOVER)

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/17/84	6	No	3	26	4	Could not command the desired turn rate; in other words, a tendency to overshoot.
1/17/84	7	Yes	3	3	5	The desired turn rate could be commanded, could be (once established), modulated as necessary to speed it up or slow it down. Tendency to overshoot and for aircraft to want to continue in existing direction.
1/17/84	8	Yes	3	11	4	The trend of turn rate was there. The primary problem of difficulty was in arresting the heading on the aircraft on the desired heading. Tendency again to overshoot and to bicycle a bit. Low frequency of rather large magnitudes.
1/17/84	1	No	1	8	4	Tendency to PIO. Very slow frequency and some minor overshoots of yaw. Light friction on collective. Seems to drift, difficulty in looking at the PMD and trying to keep my position on the outside and staying on the point.
1/17/84	2	Yes	1	7	4	Controls are a bit sensitive and tend to overshoot. Increased pilot workload, moderate compensation. No apparent torque differential across pedals.
1/17/84	3	No	1	18	7	Pitch and roll sensitivity same as before; however, yaw sensitivity increased considerably. Numerous overshoots and also very excessive rates for small pedal inputs.
1/17/84	9	Yes	3	27	3	Desired rate of turn could be easily achieved and controlled, there was a tendency to undershoot as opposed to overshoot on the desired heading. But again, the desired performance could be achieved with some ease.

TABLE G-3.- Continued

Date	Run no.	Wind turbulence	Pilot	A/C configuration	PR	Comments
1/17/84	10	No	3	34	2	The desired rate of turn could be easily achieved and could be modulated quicker or slower, and stopping on the desired heading again could easily be done with no apparent overshoot.
1/17/84	11	No	3	6	4	The desired turn rate or yaw rate could be easily established and modulated. No tendency to overshoot or undershoot the heading or to adapt to the fact that the large control displacements were required in yaw. As a corollary to that, if one is adapted to smaller magnitude control displacements correlating to some yaw rate, then it is immediately noticeable that to achieve the approximately same yaw rate you have to increase the amount that the pedals are displaced.
1/17/84	12	Yes	3	9	5.5	Substantial tendency on my part to overshoot the headings, requiring a very large opposite direction control input.
1/17/84	13	Yes	3	13	3	Large magnitude of pedal displacements required to get the aircraft moving and keep it moving.
1/17/84	14	Yes	3	7	3	Relatively easily attained and modulated small heading adjustments needed. Tendency to overshoot.
1/17/84	4	No	1	28	4	Problem maintaining the desired position over the ground within 5 ft, so position came probably in the neighborhood of 7 or 8 ft of the desired point. Rate of turns are fairly rapid and little tendency to overshoot and not get on the desired heading. High gains create high pilot workload.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/17/84	5	Yes	1	33	4	Yaw axis control was no real problem in terms of conducting the turn, stabilizing on the heading. Oscillations in yaw control, possibly PIO, show up in the turn slip indicator and HUD.
1/17/84	6	No	1	4	3	Problem in returning to the desired heading. Easier to maintain the desired position over the ground.
1/18/84	1	No	3	10	6	The ability to keep the turn rate and modulate the turn rate as you are turning is extremely difficult because of the damping.
1/18/84	2	Yes	3	33	4	Difficulty in modulating yaw rate, because of displacement required in pedals.
1/18/84	3	No	3	20	4	The desired rate could be easily attained. Tendency to overshoot the desired heading.
1/18/84	4	Yes	3	19	5	Seems to be some coupling. It seemed like there was a marked lateral drift in the aircraft. I attempted to null it out in order to maintain the approximate position. There was also a tendency to undershoot the turns going to the right, and overshoot the turns going to the left.
1/18/84	5	Yes	3	17	5	Tendency to generate higher than desired yaw rate, with a small pedal input and consequently with the damping being apparently decreased in that there was a tendency to overshoot the turn and then make a flurry of pedal inputs to try and get in under control and sustain the desired heading. Tendency to overshoot left, undershoot right.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/18/84	6	No	3	18	3	Could be accomplished with some degree of precision over it, in having it make larger than desired control displacement.
1/18/84	7	No	3	14	4	Aircraft did not want to turn. Large pedal displacements in order to make it turn. Tendency to undershoot the desired target heading.
1/18/84	8	No	3	20	3	The yaw rate could be easily attained and modulated high or slower and then rested on the desired heading without significant difficulty.
1/16/84	1	No	1	34	4	High pilot workload in the pitch and yaw. Sensitivities appear to be high. Difficulty in maintaining position over the ground.
1/16/84	2	Yes	1	13	5	Considerable pilot compensation with a very large tendency to PIO in the lateral axis. Difficulty in maintaining the position over the ground. Very difficult task requiring considerable compensation.
1/18/84	1	Yes	1	5	4	Maintaining a constant rate was a concern to me. It appears that a particular pedal input did not necessarily come up with a rate command. I started, with what I would say, slow turn right at the beginning and ended up with the rate accelerating throughout the turn requiring moderate compensation in the yaw axis to control the rate of turn. Difficult to maintain ground position.
1/18/84	2	No	1	20	3	Easy to establish a desired rate, quick response of the pedals is a nice trait. Nice characteristics in the hovering turn. Was able to maintain position over ground easily.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	3	Yes	1	3	5	Considerable compensation. Yaw rate built up very rapidly. Very hard to stabilize on the desired heading at the end of the turn. High sensitivity in pedals.
1/18/84	4	Yes	1	27	4	Perceived some drift. No problem with turn rate and things of that nature.
1/18/84	5	Yes	1	17	6	Very sensitive, undamped too. Yaw control required extensive pilot compensation. Orientation over the point for me was not possible with the yaw rate that I ended up achieving.
1/18/84	6	Yes	1	11	6	High sensitivity in the yaw axis. Again it seems to create problems, as far as I am concerned. Crawling out of the desired heading with a good roll rate or yaw rate established extensive pilot compensation. And, once on the heading again, extensive pilot compensation required to maintain that heading.
1/18/84	10	No	3	12	4	The desired rate could easily be obtained. Some slight difficulty in modulating the rate, slowing or speeding it up and stopping on the desired heading.
1/18/84	11	Yes	3	25	4	The desired rate could be achieved or it could be modulated and arrested on the desired heading without intolerable workload.
1/18/84	12	Yes	3	5	3	Relatively easily accomplished. Damping and control sensitivity reasonably matched. The aircraft is not as quick as might necessarily be desired. I'd like the time constant to be a little shorter on this, but nonetheless the turns were easily established and did not affect the stationkeeping task.
1/18/84	13	No	3	14	3	Easily accomplished, no real major problem.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/18/84	14	No	3	40	3	Because of the slowness of the yaw rate at full control defection, stationkeeping could be very, very precise. You have the ability to stop and start the yaw rate. There was really only one yaw rate that you could obtain, stopping on the desired heading could be easily accomplished.
1/18/84	15	No	3	32	3	No problem whatsoever.
1/19/84	1	No	3	24	3	No real tendency to overcontrol or over- or undershoot the desired heading.
1/19/84	2	Yes	3	31	3	I could get the rate I wanted, modulate the rate slower or faster, and stop on the desired heading. There was no tendency to overshoot. However, it did not seem to respond as quickly as perhaps was desired.
1/19/84	3	Yes	3	24	4	Larger than desired pedal displacements to generate the yaw rate. The desired yaw rate could be modulated. Slow or faster, it did require relatively larger pedal displacements in some other configurations.
1/19/84	4	Yes	3	15	4	Not any great workload as far as the directional axis is concerned. In yawing aircraft, in generating the yaw rate it seemed like it was inducing a translation about the area, requiring considerable workload as far as the cyclic was concerned in trying to maintain the hover position.
1/19/84	5	Yes	3	23	3	Not much different than previous configuration except required less effort as the translation was of a lesser magnitude.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	6	Yes	3	39	3	Less of a tendency to translate while yawing. Could easily concentrate or split concentration between stationkeeping and going up to the heading, maintaining a constant yaw rate and stopping on the desired heading.
1/19/84	7	No	3	30	3	Starting with run 5, I started using the trim button more, push release button and ensuring once I got that, I'd hit it a couple times to make sure that I had it all squared away, and then I'd do the pedal turns. I found in doing that I'm translating all over the place. I had not been doing that as much in the previous run. Could easily do low turn.
1/19/84	8	No	3	22	3	I could accurately stationkeep to make the turns, modulate the rates, stop on the desired headings and still remain precise in staying in the bob-up position.
1/19/84	9	Yes	3	16	3	In this particular case, did not re-trim and did the turns and was still able to maintain precise stationkeeping, so trimming doesn't seem to be a factor.
1/19/84	10	Yes	3	53	4	Other than the fact that they are highly sensitive, could generate larger rates very easily. Had the tendency to go back and forth on the pedals, in order to maintain the desired yaw rate.
1/19/84	11	Yes	3	57	9	In trying to obtain a rapid yet controlled rate, control was in question. Significant tendency to overcontrol the aircraft. Not able to maintain performance standard and actually did descend into the ground while trying to maintain and control the aircraft.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/19/84	12	Yes	3	51	3	There was a snappiness, a good crispness to the yaw rate. I was able to control it while keeping it going, speed it up, slow it down, stop on the desired heading. No real tendency to over- or undershoot the desired heading. Some tendency to translate in position over the surface, however certainly controllable without any major work load.
1/19/84	2	No	2	12	3	Problems looking at PMD. Tendency to go faster and turn greater than what I really had.
1/19/84	3	Yes	2	17	3	Task was easy but display setup limited performance. Problems with position control. A lot of jerking, necessitating more control applications to cyclic. Tendency to overcontrol.
1/23/84	1	Yes	2	7	4	Desired performance requiring moderate pilot compensation and a little bit of difficulty with position retention. The aircraft wanting to drift, primarily laterally, it seemed like in the turn. I would perceive the velocity vector moving out to the side, but the sensitivity seemed to be such that it took quite a bit of lateral stick to correct for that.
1/23/84	2	No	2	26	2.5	Quite easy. Virtually no altitude control necessary. Biggest workload was trying to keep a stable rate of turn and I kept several times trying to change the rate or to decrease it a little bit based upon what I saw visually. Satisfactory without improvement.
1/23/84	3	Yes	2	13	3	It took more pedal pressure to establish the turn and keep it going and I found because of that it seemed like my turn rate was slower. Position retention was worse, but still satisfactory. A lot of lateral displacement.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/23/84	4	No	2	34	3	Real comfortable, the cues were good. I felt it was much better this time just looking outside about the rate and having the overall control of the flying the airplane rather than flying the target gauge. More comfortable controlling the rate of the turn.
1/23/84	5	No	2	28	3	The rate of control seems much better looking out of the cockpit rather than using the panel-mounted display.
1/23/84	6	No	2	10	3	I felt good about the rate of turn and good about the position retention. I was able to start and stop the turns smoothly looking outside while incorporating the panel-mounted display information into the task.
1/23/84	7	Yes	2	5	4	Comfortable hover and comfortable turns, but aircraft was a little loose in attitude control. It also wobbled around a bit.
1/23/84	8	Yes	2	19	5	There was a tendency for the aircraft to slow down in the turn. There was also a tendency for the aircraft to drift away from the pivot point. I was not perceiving the drift visually, although it seemed significant on the PMD. I frequently had to chase the drift correction.
1/24/84	1	Yes	1	19	4	Very nice crispness in generating a good yaw rate. Moderate compensation is required to stabilize at the desired heading with only one or two overshoots.
1/24/84	2	Yes	1	9	7	Once you put the pedal input in, a rapid yaw rate builds up. It takes a considerable amount of opposite pedal input to stop the yaw rate and there's a tendency to overshoot numerous times before you're able to stabilize on a heading.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/24/84	3	Yes	1	25	5	You can pretty much stabilize in the desired heading. Small overshoots required considerable compensation in the yaw axis.
1/24/84	4	No	1	12	4	It was very easy to stabilize on the desired turn rate.
1/24/84	5	Yes	1	39	4	Very easy to stop on desired heading. Aircraft did not generate the kind of rates that I would like to see.
1/24/84	6	No	1	22	4	Very easy to roll out on desired heading, although I cannot generate the kind of yaw rates that I would like to see with full pedal input.
1/24/84	1	No	2	6	4	The ability to stop on a precise heading was pretty good.
1/24/84	2	No	2	8	3	Became slightly confused between the motion cues and the cues displayed on the PMD.
1/24/84	3	No	2	4	3	Aircraft characteristics were excellent, but I became confused when trying to use both outside visual cues and the PMD simultaneously.
1/24/84	5	No	4	4	3	Was able to get satisfactory performance.
1/24/84	6	Yes	4	18	3	Did not overshoot or lag much during the pedal turns.
1/24/84	7	No	4	12	7	Very small amounts of pedal input caused large yaw rates. All of my attention was directed to that aspect; therefore, altitude and position degraded.
1/24/84	10	No	4	26	3	No problems in making the low hover turns.
1/24/84	11	No	4	6	3	Was able to maintain exact position over the ground, but yaw rate was slower.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/24/84	12	No	4	20	3	It only took a small amount of pedal to get the turn going. There wasn't a lot of lag in it, and I was able to generate the rate reasonably well and stop it without moving away from the reference point.
1/24/84	13	Yes	4	13	7	I kept fixating on trying to maintain position over the ground, thereby letting all other control tasks deteriorate.
1/24/84	14	Yes	4	27	7	Yaw axis by itself was not that high a workload. But with the wind factored in controlling all of the axis, precise control of the yaw axis was degraded somewhat.
1/24/84	15	Yes	4	19	7	I wasn't able to maintain position or altitude while initiating the hover turns.
1/24/84	16	Yes	4	9	8	Was trying hard just to maintain aircraft control.
1/24/84	2	No	2	14	4	Pedal displacement and pressure was a little bit high, which resulted in a rather slow turn.
1/25/84	3	Yes	2	9	7	I thought the sensitivity of the pedals was way too high. I wasn't able to modulate the pedals such that I could ever get to a steady state in yaw. The pedal predictability was bad.
1/25/84	4	No	2	20	3	The yaw coordination, the pedal pressure, and force required for a steady rate turn was very good. I was able to modulate the forces and change the turn rate to get just what I wanted quite easily. I was also able to stop exactly where I wanted to.
1/25/84	5	Yes	2	27	4	Just a slight bit of difficulty in modulating the turn rate due to the added wind/turbulence.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/25/84	6	Yes	2	33	6	I seemed able to establish a turn and keep a fairly constant turn rate going and stop it where I wanted to, but there was extensive compensation in trying to maintain aircraft position at the same time.
1/25/84	1	No	1	30	2	Very easy to stabilize on the desired heading, and also very easy to generate the kind of rates I like to see with pedal displacement.
1/25/84	2	No	1	28	3	Very easy to generate desired rates and roll out on the desired heading.
1/25/84	3	Yes	1	21	4	I didn't like the maximum pedal rates--the sensitivity is too low. There is a tendency to overshoot once you get to the desired heading.
1/25/84	1	Yes	4	11	5	I didn't feel that I was as much in control of the yaw rate as I would like, but I was able to accomplish the task.
1/25/84	2	No	4	28	3	A small amount of pedal gave me an appropriate amount of yaw rate that I was used to and was able to control.
1/26/84	1	Yes	2	25	5	Altitude control was somewhat of a problem in ground effect. I used the panel-mounted display probably 80% of the time.
1/26/84	2	Yes	2	11	3	Primarily used panel-mounted display for the maneuver.
1/26/84	3	No	2	18	6	The yaw rate was a problem. Because of the sensitivity of the pedals, a very slight input caused the yaw axis to go too fast. It was kind of difficult to slow it down or change it.
1/26/84	4	Yes	2	3	7	It takes a lot of pedal pressure and displacement to stop the yaw response or to modulate it. It is very unpredictable.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbu-lence	Pilot	A/C config-uration	PR	Comments
1/26/84	5	Yes	2	38	4	The yaw rate once established was all right. I felt, though, that there was too much pedal pressure when I wanted to make a pedal input.
1/26/84	6	Yes	2	29	4	The yaw rate was basically fine, but the ability to modulate and change the yaw rate was not as good as I would like it to be.
1/26/84	1	Yes	1	29	5	I liked the crispness with which you can build up a yaw rate, but I feel the pedals are a bit too sensitive.
1/26/84	2	Yes	1	13	4	It is very easy to generate the kind of yaw rates that I would like to see and it is also very easy to stabilize on the desired heading with very little overshoot.
1/26/84	3	No	1	40	5	Very nice to get a rapid acceleration and end up with a high constant rate. However, when you want to stop on a desired heading you end up with several overshoots of ±6-8°.
1/26/84	4	Yes	1	23	5	The pedal sensitivity was just a little bit too much and the rate of washout into a constant rate turn was too quick. There is also a tendency to overshoot when rolling out on the desired heading.
1/26/84	5	Yes	1	32	4	I would like to be able to move the aircraft in the yaw axis a little bit faster.
1/26/84	6	Yes	1	15	5	Able to establish on desired heading without any overshoots or minimal overshoots in magnitude, but very hard to maintain position over the ground. I would like to see increased sensitivity in the pedals.

TABLE G-3.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/26/84	7	No	1	24	4	Damping looks good, but I would like to see a little bit more rate for the amount of pedal displacement.
1/26/84	8	Yes	1	31	4	Initial accelerations are good, but I still don't have the kind of yaw rates that I would like to see.
1/26/84	9	Yes	1	15	4	Damping is very good. Easy to roll out on heading, but I would like to see an increase in the yaw rate.
1/26/84	10	Yes	1	55	6	Very easy to build up a very rapid rate (even excessive). To arrest that rate, it required extensive pilot workload.
1/26/84	1	Yes	4	39	4	I put in pedal, the rate would build up nicely and then would fall off. I would have to put in more pedal to get the rate up to where I wanted it.
1/26/84	2	No	4	30	4	I had to put in more pedal than I thought I should to get the thing turned. Once the rate built up, it was where I wanted it.
1/26/84	3	Yes	4	37	4	A little bit more pedal than I would like to have to put in to build up the yaw rate, but the yaw rate got there reasonably fast and stayed there.
1/26/84	4	No	4	24	4	I was able to reasonably develop a yaw rate, but the pedals felt a tad sluggish.
1/26/84	5	Yes	4	21	4	I felt that I got an inadequate yaw rate even though it stayed reasonably constant.
1/26/84	6	No	4	40	4	Not as quick or crisp as I would like, but once the rate built up it was predictable. I also had to fine tune the pedals to get the performance I wanted.

TABLE G-3.- Concluded

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/26/84	7	No	4	22	4	I had to put in a lot of pedal to get the amount of turn rate that I wanted and I was not able to precisely control the heading.
1/26/84	8	Yes	4	23	5	There was a lack of precision in the pedals. The amount of pedal required throughout the turn varied.
1/26/84	9	Yes	4	51	5	It had to continually make small to medium corrections in the pedals in order to keep the turn going.
1/26/84	10	No	4	54	5	A given amount of pedal would develop a yaw rate and then that rate would seem to wander off or speed up depending on where I was in the turn.
1/26/84	11	No	4	52	5	The cyclic workload forced me to slow the turn rate down.
1/26/84	12	Yes	4	55	5	Because of the type of control system, I had to do the task a lot slower.
1/26/84	13	No	4	58	5	The cyclic work load caused me to degrade my yaw performance.

TABLE G-4.- PILOT COMMENTS ON TASK 4 (HIGH HOVER)

Date	Run no.	Wind/ turbu-lence	Pilot	A/C config-uration	PR	Comments
1/17/84	6	No	3	26	3	No question of good controllability.
1/17/84	7	Yes	3	3	5	The desired turn rate could be commanded once established, and modulated as necessary to speed it up or slow it down. Tendency to overshoot--desire for aircraft to want to continue in existing direction. Loss of visual near field cues that help you target on the desired heading increased pilot workload.
1/17/84	8	Yes	3	11	4	The trend of turn rate was there. The primary problem of difficulty was in arresting the heading on the aircraft on the desired heading. Tendency to over-shoot and to bicycle a bit. Low fre-quency of rather large magnitude.
1/17/84	1	No	1	8	4	Tendency to PIO. Very slow frequency and some minor overshoots of yaw. Light friction on collective. Seems to drift. Difficulty in looking at the PMD and trying to keep my position on the outside and staying on the point.
1/17/84	2	Yes	1	7	3.5	Controls are a bit sensitive and tend to overshoot. Increased power workload, moderate compensation. No apparent torque differential across pedals.
1/17/84	3	No	1	18	7	Takes a high-pilot workload to maintain the desired heading with power change compared to other configurations. Increased yaw sensitivity. Numerous overshoots and also very excessive rates for small pedal inputs.
1/17/84	9	Yes	3	27	3	Desired rate of turn could be easily achieved and controlled. There was a tendency to undershoot as opposed to overshoot on the desired heading. But again, the desired performance could be achieved with some ease.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/17/84	10	No	3	34	3	The desired rate of turn could be easily achieved and could be modulated quicker or slower, and stopping on the desired heading again could easily be done with no apparent overshoot. Primarily the loss of near field keys from the imagery due to out of ground effect hovering tended to degrade ability to hold heading.
1/17/84	11	No	3	6	4	The desired turn rate or yaw rate could be easily established and modulated. No tendency to overshoot or undershoot the heading or to be adapted to the fact that the large control displacements were required in yaw. As a corollary to that, if one is adapted to smaller magnitude control displacements corre- lating to some yaw rate, then it is immediately noticeable to achieve the same yaw rate you have to increase the amount that the pedals are displaced.
1/17/84	12	Yes	3	9	5.5	More concentration required to get the desired heading performance. Tendency to overshoot.
1/17/84	13	Yes	3	13	3	No real significant difficulty or intol- erable work load.
1/17/84	13	Yes	3	7	4	Relatively easily attained and modu- lated. Small heading adjustments needed. Tendency to overshoot. Increase in workload due to loss of near field visuals, and hence visual cues.
1/17/84	4	No	1	28	4	Rate of turns are fairly rapid and little tendency to overshoot and not get on the desired heading. High gains create high pilot workload. Difficult to maintain desired altitude.
1/17/84	5	Yes	1	33	4	Didn't seem to be a problem as far as the yaw control.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/17/84	6	No	1	4	3	Problem in returning to the desired heading.
1/18/84	1	No	3	10	6	The ability to keep the turn rate and modulate the turn rate as you are turn- ing is extremely difficult.
1/18/84	2	Yes	3	33	4	Difficulty in modulation yaw rate because of large displacements.
1/18/84	3	No	3	20	4	The desired rate could be easily attained and was potentially desired. Tendency to overshoot the desired heading.
1/18/84	4	Yes	3	19	5	Seems to be some coupling. It seemed like there was a marked lateral drift in the aircraft. It attempted to be nulled out in order to maintain the approximate position. There was also a tendency to undershoot the turns going to the right and overshoot those to the left.
1/18/84	5	Yes	3	17	5	Tendency to generate higher than desired yaw rate, with a small pedal input and consequently with the damping being apparently decreased it appeared that there was a tendency to overshoot the turn and then a flurry of pedal inputs to try and get under control and sustain the desired heading. Tendency to overshoot left and undershoot right.
1/18/84	6	No	3	18	4	Tendency to overshoot and undershoot the turn.
81/18/84	7	No	3	14	4	Aircraft did not want to turn. Large pedal displacements in order to make it turn. Tendency to undershoot the desired target heading.
1/18/84	8	No	3	20	3.5	A bit more work than the low turn; still within a tolerable limit.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/16/84	1	No	1	34	4	High pilot workload in the pitch and yaw axis. Sensitivities appear to be high. Difficulty in maintaining position over the ground.
1/16/84	2	Yes	1	13	5	Considerable pilot compensation with a very large tendency to PIO in the lateral axis. Difficulty in maintaining the position over the ground. Very difficult task requiring considerable compensation.
1/18/84	1	Yes	1	5	4	Maintaining a constant rate was a concern to me. It appears that a particular pedal input did not necessarily come up with a rate command. Difficult to maintain ground position.
1/18/84	2	No	1	20	3	Easy to establish a desired rate. Quick response of the pedals is a nice trait. Nice characteristics in the hovering turn. Was able to maintain position over ground easily.
1/18/84	3	Yes	1	3	5	Considerable compensation. Yaw rate built up very rapidly. Very hard to stabilize on the desired heading at the end of the turn. High sensitivity in pedals.
1/18/84	4	Yes	1	27	4	Perceived some drift. No problem with turn rate and things of that nature.
1/18/84	5	Yes	1	17	6	Very sensitive, undamped too. Yaw required extensive pilot compensation. Orientation over the point, for me, was not possible with the yaw rate I ended up achieving.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	6	Yes	1	11	6	High sensitivity in the yaw axis. Again it seems to create problems, as far as I am concerned. Crawling out of the desired heading with a good roll rate or yaw rate established extensive pilot compensation. And, once on the heading again, extensive pilot compensation required to maintain that heading.
1/18/84	10	No	3	12	3.5	Easier as far as obtaining precision in starting and stopping the aircraft on the desired heading.
1/18/84	11	Yes	3	25	4	Not appreciably different from the low turns. Did feel some lateral, some perceived lateral oscillations shaking the aircraft. Means that the linear not angular type oscillations, perhaps indicative of turbulence. Orientation over the point for me was not possible with the yaw rate that I ended up achieving.
1/18/84	6	Yes	1	11	6	High sensitivity in the yaw axis. Again it seems to create problems, as far as I am concerned. Crawling out of the desired heading with a good roll rate or yaw rate established extensive pilot compensation. And, once on the heading again, extensive pilot compensation required to maintain that heading.
1/18/84	10	No	3	12	3.5	Easier as far as for precision in starting and stopping the aircraft on the desired heading.
1/18/84	11	Yes	3	25	4	Not appreciably different from the low turns. Did feel some lateral, some perceived lateral oscillations shaking the aircraft--means that the linear not angular type oscillations, perhaps indicative of turbulence or whatever, those did not affect the performance of the task.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	12	Yes	3	5	3	Relatively easily accomplishe.d. No problem starting and stopping the turn.
1/18/84	13	No	3	14	3	No noticeable difference in the ability to do the turns in-ground effect or outer-ground effect.
1/18/84	14	No	3	40	3	Desired heading could be easily obtained.
1/18/84	15	No	3	32	3	No problem whatsoever.
1/19/84	1	No	3	24	3	No real tendency to overcontrol or over- or undershoot the desired heading.
1/19/84	2	Yes	3	31	3	I could get the rate I wanted to, modulate the rate slower or faster, and stop on the desired heading. There was no tendency to overshoot. However, it did not seem to respond as quickly as perhaps was desired.
1/19/84	3	Yes	3	24	4	Larger than desired pedal displacements.
1/19/84	4	Yes	3	15	4	Not any great workload as far as the directional axis is concerned. In generating the yaw rate it seemed like it was importing a translation about the area requiring considerable workload as far as the cyclic is concerned in trying to maintain the hover position.
1/19/84	5	Yes	3	23	3	Not much different than previous configuration except required less effort as the translation was of a lesser magnitude.
1/19/84	6	Yes	3	39	3	Less of a tendency to translate while yawing. Could easily concentrate or split concentration between stationkeeping and going up to the heading, maintaining a constant yaw rate and stopping on the desired heading.
1/19/84	7	No	3	30	3	Could easily do high turn and stay within 5-10 ft of the desired location.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	8	No	3	22	3	I could accurately stationkeep to make the turns, modulate the rates, stop on the desired headings and still remain precise in staying in the bob-up position.
1/19/84	9	Yes	3	16	3	In this particular case did not re-trim and did the turns and was still able to maintain precise stationkeeping, so trimming doesn't seem to be a factor.
1/19/84	10	Yes	3	53	4	Other than the fact that they are highly sensitive, could generate larger rates very easily. Had the tendency to go back and forth on the pedals in order to maintain the desired yaw rate.
1/19/84	11	Yes	3	57	7	Had to work substantially to get the kind of performance I wanted. Tendency to overcontrol and overshoot.
1/19/84	12	Yes	3	51	3	There was a snappiness, a crispness to the yaw rate. I was able to control it while keeping it going, slowing it down, speeding it up, stopping on the desired heading. No real tendency to over- or undershoot the desired heading. Some tendency to translate a position over the surface. However, certainly controllable with no major pilot workload.
1/19/84	2	No	2	12	3	Problems looking at PMD. Tendency to go faster and turn greater than what I really had.
1/19/84	3	Yes	2	17	3	Task was easy but display set-up limited performance. Problems with position control. A lot of jerking--necessitated more control applications to cyclic. Tendency to overcontrol.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/23/84	1	Yes	2	7	4	Desired performance requiring moderate pilot compensation and a little bit of difficulty with position retention--the aircraft wanting to drift, primarily laterally, it seemed like in the turn. I would perceive the velocity vector moving out to the side, but the sensitivity seemed to be such that it took quite a bit of lateral stick to correct for that.
1/23/84	2	No	2	26	2.5	Quite easy. Virtually no altitude control necessary. Biggest workload was trying to keep a stable rate of turn and I kept trying to change the rate or to decrease it a little bit based upon what I saw visually. Satisfactory without improvement.
1/23/84	3	Yes	2	13	3	It took more pedal pressure to establish the turn and keep it going and I found because of that, it seemed like my turn rate was slower. Position retention was worse, but still satisfactory. A lot of lateral displacement.
1/23/84	4	No	2	34	3	Cues weren't as good as for low hover. It felt quite good.
1/23/84	5	No	2	28	3	The rate of control seems much better looking out of the cockpit rather than using the panel-mounted display.
1/23/84	6	No	2	10	3	I felt good about the rate of turn and good about the position retention. I was able to start and stop the turns smoothly looking outside while incorporating the panel-mounted display information into the task.
1/23/84	7	Yes	2	5	3	There was no vibration or wobbling at all.
1/23/84	8	Yes	2	19	4	I spent more time looking at the PMD and was able to make adequate drift corrections.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/24/84	1	Yes	1	19	4	Very nice crispness in generating a good yaw rate. Moderate compensation is required to stabilize at the desired heading with only one or two overshoots.
1/24/84	2	Yes	1	9	7	Once you put the pedal input in, a rapid yaw rate builds up. It takes a considerable amount of opposite pedal input to stop the yaw rate, and there's a tendency to overshoot numerous times before you're able to stabilize on a heading.
1/24/84	3	Yes	1	25	5	You can pretty much stabilize in the desired heading. Small overshoots required considerable compensation in the yaw axis.
1/24/84	4	No	1	12	4	It was very easy to stabilize on the desired turn rate.
1/24/84	5	Yes	1	39	4	Very easy to stop on the desired heading. Aircraft did not generate the kind of rates that I would like to see.
1/24/84	6	No	1	22	4	Very easy to roll out on the desired heading, although I cannot generate the kind of yaw rates that I would like to see with full pedal input.
1/24/84	1	No	2	6	4	The ability to stop on a precise heading was good. I felt that the position retention was a bit off due to the lack of visual cues.
1/24/84	2	No	2	8	3	Became slightly confused between the motion cues and the cues displayed on the PMD.
1/24/84	3	No	2	4	3	Spent more time on the PMD due to the lack of outside visual cues.
1/24/84	5	No	4	4	3	Had no problem in keeping the aircraft within the constraints box.
1/24/84	6	Yes	4	18	3	Did not overshoot or lag much during the pedal turns.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/24/84	7	No	4	12	7	Very small amounts of pedal input caused large yaw rates. All of my attention was directed to that aspect, therefore A/C altitude and horizontal position suffered.
1/24/84	10	No	4	26	3	No problem making the high hover turn.
1/24/84	11	No	4	6	3	Lack of visual cues did not compromise my ability to hold over a single point while doing the turn.
1/25/84	3	Yes	2	9	7	I thought the sensitivity of the pedals was way too high. I wasn't able to modulate the pedals such that I could ever get to a steady state in yaw. The pedal predictability was very bad.
1/25/84	4	No	2	20	3	The yaw coordination, the pedal pressure, and force required for a steady rate turn was very good. I was able to modulate the forces and change the turn rate to get just what I wanted.
1/25/84	5	Yes	2	27	4	Just a slight bit of difficulty in modulating the turn rate due to the added wind/turbulence.
1/25/84	6	Yes	2	33	6	I seemed able to establish a turn and keep a fairly constant turn rate going and stop it where I wanted to, but there was extensive compensation in trying to maintain aircraft position at the same time.
1/25/84	1	No	1	30	2	Very easy to stabilize on the desired heading, and also very easy to generate the kind of rates I like to see with pedal displacement.
1/25/84	2	No	1	28	3	Very easy to generate desired rates and roll out on the desired heading.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/25/84	3	Yes	1	21	4	I didn't like the maximum pedal rates. The pedal sensitivity is too low. There is a tendency to overshoot once you get to the desired heading.
1/25/84	1	Yes	4	11	7	While performing the task I could not maintain tolerances that were respective of adequate performance.
1/25/84	2	No	4	28	3	A small amount of pedal gave me the appropriate amount of yaw rate that I was used to and was able to control.
1/26/84	1	Yes	2	25	5	The pilot workload was somewhat affected by the requirement to pay a little more attention to altitude.
1/26/84	2	Yes	2	11	3	Primarily used panel-mounted display for the maneuver.
1/26/84	3	No	2	18	6	The yaw rate was a problem because of the sensitivity of the pedals; a very slight input caused the yaw axis to go too fast. It was kind of difficult to slow it down or change it.
1/26/84	4	Yes	2	3	7	It takes a lot of pedal pressure and displacement to stop the yaw response or to modulate it. It is very unpredictable.
1/26/84	5	Yes	2	38	4	I felt too much pressure in the breakout forces when I wanted to make pedal inputs.
1/26/84	6	Yes	2	29	4	There was kind of a disharmony in forces required for the turns in both directions.
1/26/84	1	Yes	1	29	5	I tended to overshoot one or two oscillations before stabilizing on the desired heading. This aspect required considerable pilot compensation.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/26/84	2	Yes	1	13	4	It is very easy to generate the kind of yaw rates that I would like to see and it is also very easy to stabilize on the desired heading with very little overshoot.
1/26/84	3	No	1	40	5	Very nice to get a rapid acceleration and end up with a high constant rate.
1/26/84	4	Yes	1	23	5	The pedal sensitivity was just a little bit too much and the rate of overshoot into a constant rate turn was too quick. There is also a tendency to overshoot when rolling out on the desired heading.
1/26/84	5	Yes	1	32	4	I would like to be able to move the aircraft in the yaw axis a little bit faster.
1/26/84	6	Yes	1	15	5	Able to establish on desired heading without any overshoots or minimal overshoots in magnitude, but very hard to maintain position over the ground. I would like to see increased sensitivity in the pedals.
1/26/84	7	No	1	24	4	Damping looks good, but I would like to see a little bit more rate for the amount of pedal displacement.
1/26/84	8	Yes	1	31	4	Initial accelerations are good, but I still don't have the kind of yaw.
1/26/84	9	Yes	1	15	4	Damping is very good. Easy to roll out on heading, but I would like to see an increase in the yaw rate.
1/26/84	10	Yes	1	55	6	Very easy to build up a very rapid rate (even excessive). To arrest that rate it required extensive pilot workload.
1/26/84	1	Yes	4	39	4	I had to continually fine tune the pedals to get the yaw rate where I wanted it.

TABLE G-4.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/26/84	2	No	4	30	4	I had to put in more pedal than I thought I should to get the aircraft turned. Once the rate built up, it was where I wanted it.
1/26/84	3	Yes	4	37	4	A little bit more pedal than I would like to have to put in to build up the yaw rate, but the yaw rate got there reasonably fast and stayed there.
1/26/84	4	No	4	24	4	The yaw control wasn't quite as precise as I thought it should be.
1/26/84	5	Yes	4	21	5	The workload was greater in the pedals because I felt that I had to change pedal position to maintain the desired yaw rate.
1/26/84	6	Yes	4	40	4	No particular difference between this and the low hover turn. Not as quick or crisp as I would like.
1/26/84	7	No	4	22	4	I had to put in a lot of pedal to get the amount of turn rate that I wanted and I was not able to precisely control the heading.
1/26/84	8	Yes	4	23	5	The effect of weathercock stability was more apparent than during the in-ground-effect hover.
1/26/84	9	Yes	4	51	5	I had to continually make small to medium corrections in the pedals in order to keep the turns going.
1/26/84	10	No	4	54	5	The weathercock tendency was worse than the low hover but the work load was not any more extensive.
1/26/84	11	No	4	52	5	The cyclic workload forced me to slow my turn rate down. I instinctively brought down the yaw rate until I could get the aircraft under control.
1/26/84	12	Yes	4	55	6	I let the yaw rates build up too fast.

TABLE G-4.- Concluded

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/26/84	13	No	4	58	5	The cyclic workload caused me to degrade my yaw performance.

TABLE G-5.- PILOT COMMENTS ON TASK 5 (TARGET ACQUISITION)

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/17/84	6	No	3	26	5	Tendency to overshoot and have to come back. Compromise to performance of that one and while the desired rate of quickness was there, the tendency to overshoot it is what has caused the tracking problem.
1/17/84	7	Yes	3	3		Not rated.
1/17/84	8	Yes	3	11	5	Tendency to overshoot caused difficulty in maintaining the retical on the target.
1/17/84	1	No	1	8	5	Ran out of fingers to control all the functions on the cyclic stick. I had to release the force gradient disable switch to move to the attack display mode and then had to use the same to hit the missile fire switch, resulting in a late fire. If you want to fly with the force gradient off you have to use your thumb and workload goes up considerably.
1 17/84	2	Yes	1	7	4	Easy to acquire the target as the left gradient was on. Target easily tracked initially as well. Tendency to overshoot when swinging around to acquire the target. Aircraft tends to drift a bit too much.
1/17/84	3	No	1	18		No comments.
1/17/84	9	Yes	3	27	3	Apparent vibrations perceived while flight did not adversely affect the stationkeeping task.
1/17/84	10	No	3	34	2	Controllability not a problem.
1/17/84	11	No	3	6		No comment.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/17/84	12	Yes	3	9	6	Sensitive. The task of arresting the yaw rate and getting it going in the opposite direction to follow along with the task required considerable effort with a tendency to overshoot. Control reversals and the magnitude of the pedal displacements and trying to arrest the turn rate in one direction and immediately get it started in another were bad.
1/17/84	13	Yes	3	13	4	Best performance so far as the ability to keep the retical on the air target, where there is learning on my part because of the apparent sluggishness of the aircraft. There is less of a tendency to overshoot in trying to rapidly displace the nose on the retical in the vicinity of the target and then fine trim.
1/17/84	14	Yes	3	7	4	Seeming lateral shake in the aircraft. Initially commanding a rather large yaw, a high rate yaw excursion, arresting it, and then going back to tracking the air-to-air target. No tendency to overshoot. Damping appeared adequate.
1/17/84	4	No	1	28	5	Did acquire target in cross hairs. Difficult to release the force gradient and have full control of the aircraft and I am physically limited in the ability to re-orient the head depth display to fire power and also to launch the missile, and that I cannot disable the force gradient and perform those two functions simultaneously.
1/17/84	5	Yes	1	33		Not rated.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu-lence	Pilot	A/C config-uration	PR	Comments
1/17/84	6	No	1	4	4	Tendency to overshoot through the target before you could stabilize on the target. Once stabilized on the target, you get the perspective of the velocity of which the target is moving across the front. Tracking ability becomes considerably easier. Initial acquisition is a real problem there. Moderate pilot compensation required.
1/18/84	1	No	3	10	6	Tendency to overshoot with large magnitude pedal displacements at a full control motion, at moderate frequency back and forth.
1/18/84	2	Yes	3	33	4	Because of the large pedal displacements, there was a tendency to undershoot, or perhaps overshoot, essentially lagging the target in trying to track, because of pedal motions.
1/18/84	3	No	3	20	5	Tendency to under- and overshoot the target while trying to maintain the necessary yaw rate to track it.
1/18/84	4	Yes	3	19	4	Marked tendency to undershoot and you had to sort of creep up to it to place the retical on the target.
1/18/84	5	Yes	3	17	5	Tendency to overshoot the target and in recognizing the overshoot, then the compensation would be not to put in such a large pedal input and then through the tracking task, it appeared that the retical was lagging behind the target. Relatively low apparent damping and high sensitivity.
1/18/84	6	No	3	18	4	Initial tendency to overshoot the target. A large right yaw rate imparted to the aircraft, it was arrested and then a left yaw rate was commenced to track the target. Initially, there was lagging behind the target and then I was able to modulate the rate so as to track the target.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	7	No	3	14	5.5	The tracking task was compromised by the inability for the aircraft to respond rapidly enough. The desired damping is there, but is inhibiting trying to get the aircraft to respond with any degree of rapidity, consequently always lagging behind the target with the retical.
1/18/84	8	No	3	20	3	Performance was not compromised by the directional handling capability. Rapid yaw displacement at a high rate, followed by that being arrested and then a yaw rate to the right to begin to track the target. No problems in the rate reversal; there was an initial tendency to undershoot the target.
1/16/84	1	No	1	34	4	Moderate compensation required, tendency to minor PIO in the yaw axis trying to engage the target and maintain the aircraft orientation on the target throughout the tracking task. Small roll inputs also tend to cause the slip indicator to go from large excursion outside the number lines which is very distracting in head-up display the way it's set right now.
1/16/84	2	Yes	1	13	4	Initial acquisition required moderate compensation, followed by continuous inputs in the yaw axis to maintain the desired track on the target.
1/18/84	1	Yes	1	5	5	Considerable compensation required for initial target acquisition then tracking required moderate compensation.
1/18/84	2	No	1	20	6	Tracking required extensive compensation at a range because of the high sensitivity in the pedals. You have to be very tight in the loop to ensure target acquisition and maintain the proper track.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	3	Yes	1	3	7	Maximum amount of pilot compensation required. Unable to acquire and hold the target. I had quite a tendency to overshoot. Almost undamped oscillations about the target to the point that you could not lock on.
1/18/84	4	Yes	1	27	5	Had to lower the nose of the aircraft to maintain the target aircraft in the cross, consequently resulting in a drift across the ground. Controllability in the yaw axis was there once I was able to acquire the target, I was able to maintain track on the target.
1 18/84	5	Yes	1	17	7	Unable to acquire the target within the time constraints and unable to launch a missile. Part of it was working against the force gradient contributing to high power workload, and that's part of the physical constraints in the cyclic stick--unable to disengage the force gradient while you are trying to acti- vate your fire control mode, then switch it on the cyclic or thumb operation.
1/18/84	6	Yes	1	11		Not rated.
1/18/84	10	No	3	12	4	Not appreciably degraded one way or another. Concentration required in the directional axis of the target tracking task. There was an initial tendency to overshoot. I was able then to track the target without difficulty with some tendency to bicycle on the pedals in trying to vernier the control.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/18/84	11	Yes	3	25	4.5	Stationkeeping performance was not seriously degraded by the directional handling qualities. The tracking task, however, was less than desired. Damping coupled with the apparent control sensitivity, there was a tendency in keeping the retical on the target to walk it back and forth. In the majority of times, the target was underneath the retical symbol pretty much most of the time.
1/18/84	12	Yes	3	5	4	Easily accomplished, the rate reversal yawing left, first right target initially appeared from the left was easily accomplished. It took a bit of adjustment when I verniered it and matched yaw rates and tracked the target with some ease. Still had to mentally anticipate and put in a larger than desired pedal motion.
1/18/84	13	No	3	14	3.5	Perhaps in anxiousness there is nothing more, just a tendency to overcontrol in trying to vernier the retical on the target, but got the rates matched up without a great deal of difficulty and was able to hold them and execute the launch.
1/18/84	14	No	3	40		Not completed.
1/18/84	15	No	3	32		No pilot rating.
1/19/84	1	No	3	24	4	Easily accomplished. First off, there was just a slight tendency to undershoot and I'm going to track the target.
1/19/84	2	Yes	3	31		No pilot rating.
1/19/84	3	Yes	3	24		No pilot rating.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	4	Yes	3	15	4	No significant problems. I was able to generate the desired yaw rates and match well with the target. To hold on the target was no problem.
1/19/84	5	Yes	3	23	3	The aircraft yaw rate could be matched with the target's velocity and I could rapidly acquire the target and match yaw rates and stay within sight parameters.
1/19/84	6	Yes	3	39	3	Aside from the initial distraction of the target coming in from the left, or from the right, and yawing back toward, just mental cooperation. Things had a slight tendency to overcontrol, in that regard, but I was able to match velocities and stabilize the yaw rate.
1/19/84	7	No	3	30	4	Initial slight tendency to overcontrol, overshoot the target. However, there was adequate damping in there to come back and vernier onto the target without any real tendency toward bicycling on the pedals.
1/19/84	8	No	3	22	4	A tendency to over- and undershoot on the target. A slight bicycling of the pedals and wound up with the retical lagging the target and had the vernier on. A little bit more difficult than before.
1/19/84	9	Yes	3	16	3	Slight initial tendency to overcontrol. I was able to match up on the target and keep the rates and shoot the target.
1/19/84	10	Yes	3	53	4	More tendency to overcontrol, overshoot the target, bicycle the pedals, but I was able to vernier that out and track the target. Overall control sensitivity seemed to be adequate, I certainly would not want something any more responsive with the decrease in damping.
1/19/84	11	Yes	3	57		Not rated.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/19/84	12	Yes	3	51	3	I was able to rapidly get the aircraft's nose around to track the target and match rates. One overshoot and initially matching rates, but that was in the rate direction reversal, going from a right yaw rate to a left yaw rate to match up. The rest of that I was able to adjust the retical onto the target and was able to keep the retical centered on the target throughout the engagement.
1/19/84	2	No	2	12	5	I think I'm still muddling through, trying to figure out what's really going on. Biggest workload I think is trying to mentally think about where the trees are, to get the airplane under control again and then get back to putting the pipper on the target.
1/19/84	3	Yes	2	17	6	Don't know whether I am 3 ft or 300 ft from target. Difficult to get the retical on the target and keep it on the target for more than a second or a second and a half. Marginal performance.
1/23/84	1	Yes	2	7	5	I overshot to the left and had difficulty coming back to the right. I never got a tone. I had an overshoot problem. I don't know or maybe my mind or my eyes were just a little out of foresight. Adequate performance required considerable compensation.
1/23/84	2	No	2	26	5	I thought I kept the retical on the target long enough to engage target, but probably didn't change the pitch sufficient to move up or down to get the foresight on. Inefficient performance in knowing where I am in relation to the bob-up position. Adequate performance.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/23/84	3	Yes	2	13	6	Similar to last time. It helps to back up if you don't hit the trees so fast and I'm having trouble keeping the retical on the target. I can't quickly get it on there and keep it on there in yaw control, so I'd say that the desired performance is not obtainable. Adequate performance requiring extensive compensation.
1/23/84	4	No	2	34	7	Overshot twice and was never able to get steady on the target. No positive inputs on pitch much, because I'm having a hard time on yaw. Difficulty perceiving where I am in relation to the terrain. I am unable to make small accurate displacements in the yaw axis, i.e., the A/C keeps jerking around and I can't get the pipper lined up on target.
1/23/84	5	No	2	28	7	Quickly to move over to the target but just unable to get quickly on the target and stabilize; and once I do overshoot, I am unable to make small displacements in yaw, such that I can get the pipper lined up with the target.
1/23/84	6	No	2	10	5	I was able to get the pipper on the target and keep it there fairly well within constraints.
1/24/84	2	Yes	1	9	4	The target was very easy to acquire and then track.
1/24/84	3	Yes	1	25	6	Extensive compensation in trying to acquire the target.
1/24/84	4	No	1	12	5	I can't get the pipper on the target and get a proper engagement signal.
1/24/84	1	No	2	6	5	It took me awhile to get the aircraft settled down in yaw to match the aircraft yaw response with the movement of the target aircraft.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/24/84	2	No	2	8	6	I am unable to get quickly on the target, due to the overshoots. When I finally get the yaw under control, time has run out.
1/24/84	5	No	4	4	4	Aircraft required more than normal control inputs to get the required response, even though I was able to get on target in a reasonable time.
1/24/84	6	Yes	4	18	4	When changed the collective during the task, the yaw tracking was affected. Therefore, it took too long to stabilize on target.
1/24/84	10	No	4	26	7	I kept over- and undershooting the target until I ran out of time.
1/24/84	11	No	4	6	5	I might have gotten the target if I had had more time.
1/24/84	12	No	4	20	4	It took a reasonable amount of workload to get the pipper on target, but once it was on target, it was easy to track.
1/24/84	13	Yes	4	13	5	I overshot the target twice before I could get the proper rate and put the pipper on the target.
1/24/84	14	Yes	4	27	5	The target acquisition was harder than the tracking. Once I got the pipper on the target I was surprised how easy it was to track.
1/24/84	15	Yes	4	19	5	I was quickly able to get oriented on the target and match rates, even though I had to hold an odd pitch attitude.
1/24/84	16	Yes	4	9	7	I had all kinds of control power to quickly acquire the target, but I kept overshooting it. I didn't want to fly sideways due to the high probability of hitting surrounding trees.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/25/84	2	Yes	2	14	5	I was able to get the pipper on target very easily and quickly, but I couldn't hold it on for 1 second.
1/25/84	3	Yes	2	9	7	The ability to turn and put the pipper on the target was extremely poor. I drifted considerably from where I started over the ground.
1/25/84	4	No	2	20	7	I am not able to quickly get the pipper there and keep it there. I am still making a lot of inputs and overcontrolling somewhat in pedal control.
1/25/84	5	Yes	2	27	7	I'll initially sweep through in yaw and overshoot as I try to turn toward the target. I'll either not put in enough control or too much and swing through or fall short again. The predictability of the pedal inputs is poor.
1/25/84	1	No	1	30	4	A tendency to overshoot initially due to the forced gradient. You can't disengage the force gradient and also change displays due to the controller configuration.
1/25/84	2	No	1	28	4	I don't like particularly working against the force gradient. One overshoot and then it is relatively easy to get the pipper on the target.
1/25/84	1	Yes	4	11	7	I was unable to hold very steadily on the target.
1/25/84	2	No	4	28	3	Minimal compensation. Once I got the pipper on the target, I was able to match the rate of the target helicopter, get a lock on, and get a missile shot off easily.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbulence	Pilot	A/C configuration	PR	Comments
1/26/84	1	Yes	2	25	7	I tried to go quickly to the target and was not able to stop on the target, but overshot it 20° or so. I was able to continually decrease the error, but it took what I would consider an excessive amount of time.
1/26/84	4	Yes	2	3	7	I just was unable to quickly get the pipper on target and keep it there. I was continually trying to make small corrections but I kept over- and undershooting the target.
1/26/84	5	Yes	2	38	7	I'm unable to make the correct pedal inputs to get the pipper where I want it and keep it there, or to make small corrections to quickly match my turn rate with that of the target.
1/26/84	6	Yes	2	29	4	I was just kind of wallowing around there and just happened to get the acquisition box and was able to shoot the missile.
1/26/84	1	Yes	1	29	4	Very easy to generate a rapid yaw rate to attempt to acquire the target. There was a tendency to overshoot initially due to the high sensitivity in the pedals.
1/26/84	4	Yes	1	23	6	It was very difficult to acquire the target and also the follow-on tracking was a difficult task. I seem to be experiencing control ratcheting.
1/26/84	5	Yes	1	32	4	I would like to have a quicker rate to be able to move the aircraft in the direction of the target faster. I also overshot the target several times.
1/26/84	6	Yes	1	15	4	Very aggressively went after the target and overshot it by two oscillations. Yaw control felt too damped.

TABLE G-5.- Continued

Date	Run no.	Wind/ turbu- lence	Pilot	A/C config- uration	PR	Comments
1/26/84	7	No	1	24	5	I used full right pedal deflection to rotate the aircraft in the direction of the target and went through a series of three overshoots trying to stabilize on the target. Damping was good, but I would like to be able to generate higher rates.
1/26/84	8	Yes	1	31	4	Easy to acquire and track the target.
1/26/84	9	Yes	1	15	4	Had to use full pedal deflection to swing the aircraft around to the right to engage the target, one overshoot, and then I was able to track it.
1/26/84	10	Yes	1	55	5	You can get a good rate buildup to move over to where the target is. The tendency is to overshoot quite a bit. Once you are able to dampen those oscillations down and end up with a good track, it is relatively easy to continue the tracking operation.
1/26/84	1	Yes	4	39	5	I could get the nose of the aircraft over to the target quickly with a large pedal application, but then when I wanted to reverse the direction, I overshot the target A/C. Had to match the rate with the pipper with minor pedal corrections.
1/26/84	2	No	4	30	3	It only took a couple of small movements to track the target.
1/26/84	4	No	4	24	6	I had to put in a lot of pedal to get the pipper on target. After the fourth overshoot I used the cyclic stick.
1/26/84	5	Yes	4	21	4	I was able to get the pipper on the target without resorting to using cyclic input.

TABLE G-5.- Concluded

Date	Run no.	Wind/ turbu-lence	Pilot	A/C config-uration	PR	Comments
1/26/84	6	Yes	4	40	4	It felt to me like I put in two pedal applications to get the rate going. Once I got it there, it stopped reasonably well with no real overshooting problem.
1/26/84	7	No	4	22	5	The aircraft felt too sluggish. I had to put in considerable pedal to get the nose in the direction I wanted.
1/26/84	8	Yes	4	23	5	The aircraft was sluggish when I tried to acquire the target initially.
1/26/84	9	Yes	4	51	4	I didn't notice a lack of yaw rate in acquiring the target, but there was a slight bit of hunting with the pedals when I was trying to lock on.
1/26/84	10	Yes	4	54	6	The initial response was very good, but I kept over- and undershooting the target. I finally started using cyclic to aim the aircraft.
1/26/84	11	No	4	52	4	Reasonably responsive in yaw to acquire the target.
1/26/84	12	Yes	4	55	6	I think the key to tracking with this system is attempting to acquire very rapidly and quickly match rates. I used my previous pilot strategy and that took too much time.
1/26/84	13	Yes	4	58	4	Pedals were reasonably responsive.

APPENDIX H

YAW RESPONSE DUE TO TURBULENCE

Table H-1 lists the heading response generated after the introduction of light turbulence at a hover.

TABLE H-1.- TURBULENCE RESPONSE DATA

ψ after 6 sec with no pilot input under light turbulence.

For initial conditions the aircraft is at a hover.

Wind direction is 45° to the right of the nose.

	Configuration 1	Configuration 7
PSI, deg		
Minimum =	-0.19879E 02	-0.11585E 00
Maximum =	.79183E 01	.32624E 01
rms =	.11906E 02	.22043E 01
Mean =	-.57551E 01	.18211E 01
Standard deviation =	.10423E 02	.12420E 01
N sample =	.12200E 03	.12200E 03

	Configuration 3	Configuration 9
PSI, deg		
Minimum =	-0.17142E 00	-0.17004E 02
Maximum =	.77848E 01	.14845E 01
rms =	.45972E 01	.10515E 02
Mean =	.36712E 01	-.83668E 01
Standard deviation =	.27671E 01	.63685E 01
N sample =	.12200E 03	.12200E 03

	Configuration 5	Configuration 11
PSI, deg		
Minimum =	-0.50483E 01	-0.93182E-02
Maximum =	.20181E 01	.12571E 02
rms =	.25477E 01	.76282E 01
Mean =	-.13632E 01	.59735E 01
Standard deviation =	.21524E 01	.47442E 01
N sample =	.12200E 03	.12200E 03

TABLE H-1.- Continued

Configuration 13	
PSI, deg	
Minimum =	-0.44544E 01
Maximum =	.17098E 01
rms =	.24905E 01
Mean =	-.16337E 01
Standard deviation =	.18798E 01
N sample =	.12200E 03
Configuration 15	
PSI, deg	
Minimum =	-0.23346E 01
Maximum =	.11070E 01
rms =	.11888E 01
Mean =	-.42832E 00
Standard deviation =	.11090E 01
N sample =	.12200E 03
Configuration 17	
PSI, deg	
Minimum =	0.85681E-06
Maximum =	.21797E 02
rms =	.97941E 01
Mean =	.72516E 01
Standard deviation =	.65831E 01
N sample =	.12200E 03
Configuration 19	
PSI, deg	
Minimum =	-0.35183E-02
Maximum =	.21311E 02
rms =	.10207E 02
Mean =	.74625E 01
Standard deviation =	.69636E 01
N sample =	.12200E 03
Configuration 21	
PSI, deg	
Minimum =	-0.30909E-01
Maximum =	.17240E 01
rms =	.99142E 00
Mean =	.81875E 00
Standard deviation =	.55906E 00
N sample =	.12200E 03

Configuration 23	
PSI, deg	
Minimum =	0.43257E-05
Maximum =	.39196E 01
rms =	.24569E 01
Mean =	.21469E 01
Standard deviation =	.11946E 01
N sample =	.12200E 03
Configuration 25	
PSI, deg	
Minimum =	-0.58969E 01
Maximum =	.45601E 01
rms =	.38789E 01
Mean =	-.23518E 01
Standard deviation =	.30845E 01
N sample =	.12200E 03
Configuration 27	
PSI, deg	
Minimum =	0.23463E-05
Maximum =	.42698E 01
rms =	.26211E 01
Mean =	.22622E 01
Standard deviation =	.13238E 01
N sample =	.12200E 03
Configuration 29	
PSI, deg	
Minimum =	-0.98852E 00
Maximum =	-.14825E-04
rms =	.74434E 00
Mean =	-.69351E 00
Standard deviation =	.27036E 00
N sample =	.12200E 03
Configuration 31	
PSI, deg	
Minimum =	-0.86200E 00
Maximum =	.73896E 00
rms =	.44974E 00
Mean =	-.10539E 00
Standard deviation =	.43722E 00
N sample =	.12200E 03

TABLE H-1.- Concluded

Configuration 33		Configuration 37	
PSI, deg		PSI, deg	
Minimum =	0.29140E-05	Minimum =	-0.90663E-01
Maximum =	.14554E 02	Maximum =	.25352E 01
rms =	.75263E 01	rms =	.16746E 01
Mean =	.54999E 01	Mean =	.14314E 01
Standard deviation =	.51378E 01	Standard deviation =	.86927E 00
N sample =	.12200E 03	N sample =	.12200E 03
Configuration 35		**Configuration 39**	
PSI, deg		PSI, deg	
Minimum =	-0.86260E 00	Minimum =	-0.54167E 00
Maximum =	.96953E 01	Maximum =	.65578E 00
rms =	.43558E 01	rms =	.36043E 00
Mean =	.26062E 01	Mean =	.73246E-01
Standard deviation =	.34901E 01	Standard deviation =	.35291E 00
N sample =	.12200E 03	N sample =	.12200E 03

APPENDIX I

ROOT LOCUS ANALYSIS

General transfer function (yaw axis)

$$\frac{\dot{\psi}}{\delta p}(s) = \frac{N_{\delta p} S}{S^2 - N_r S + U_o N_v \cos \psi_o}$$

U_o = 15 knots = 25 ft/sec
ψ_o = 45°
cos 45° = 0.707

The open loop poles and closed loop poles of each of the configurations are plotted on the following root loci graphs (figs. I-1 to I-20). For the closed loop system the feedback gain has the value of one where the closed loop transfer function has the form

$$\frac{\dot{\psi}}{\delta p}(s) = \frac{G(s)}{1 + G(s)H(s)}$$

τ (fig. I-21) is the predominant time constant and an alternative measure for settling time. The envelope of the transient response decays to 37% of its initial value in τ sec. For a second order system it can be approximated by $1/\zeta\omega_N$.

T_r (fig. I-21) is defined as the time required for the response to a unit step function input to rise from 10 to 90% of its final value. For a given transfer function this is done by closing the loop with a unity feedback gain. The resulting T taken from a root loci plot then becomes T_R.

After plotting T_r vs τ (system time constant) (figs. I-22 to I-23), the following conclusions may be made:

For the low hover and high hover tasks a $T_R < 0.2$ sec and $\tau < 0.6$ give the best pilot ratings.

For the air-to-air acquisition task a $T_R < 0.13$ and $\tau < 0.33$ yields the best pilot ratings.

In both cases the τ/T_R ratio remained at 2.5 ±0.25.

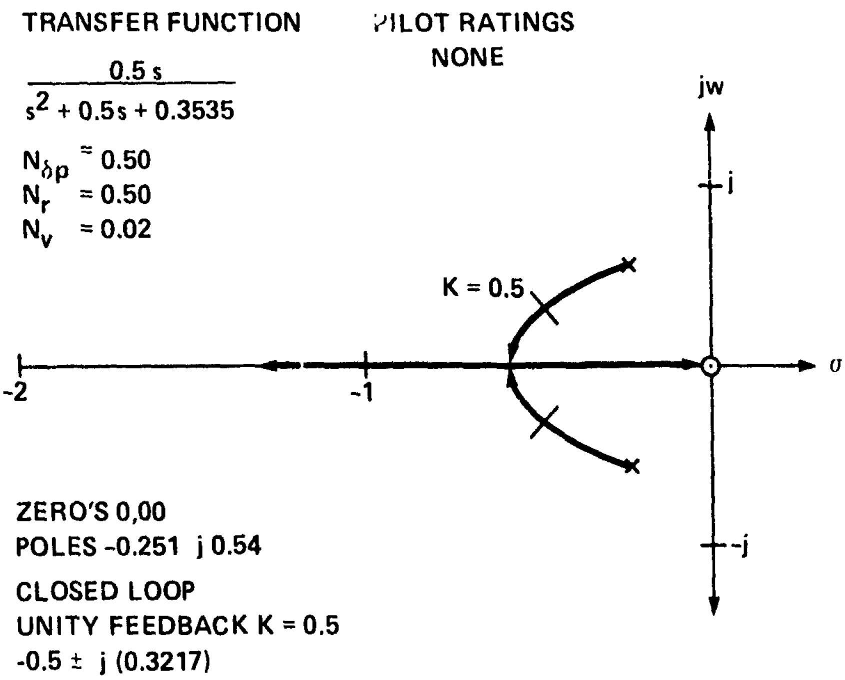


Figure I1.- Root locus plot (configuration 1).

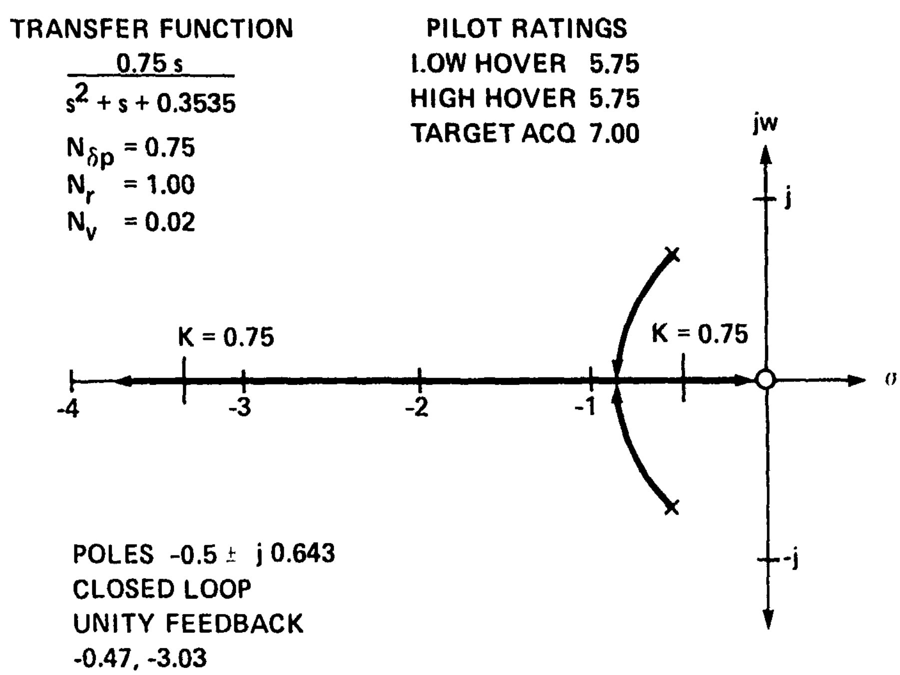


Figure I2.- Root locus plot (configuration 3).

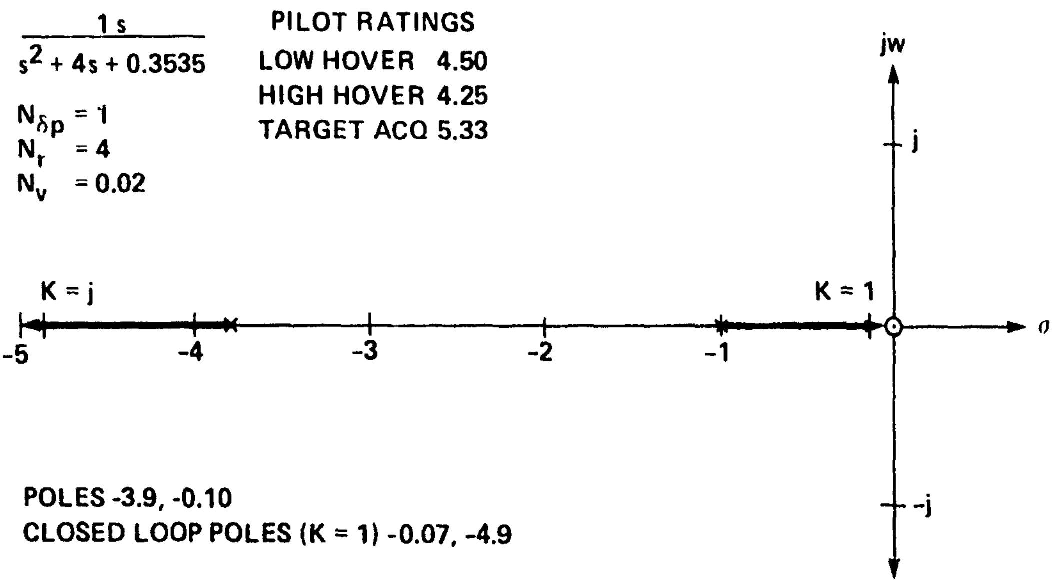


Figure I3.- Root locus plot (configuration 5).

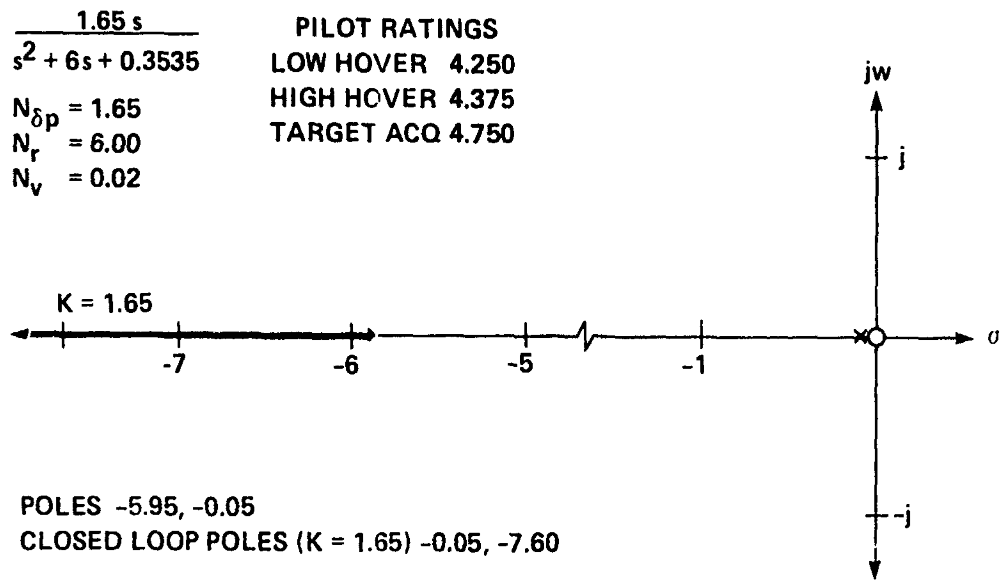


Figure I4.- Root locus plot (configuration 7).

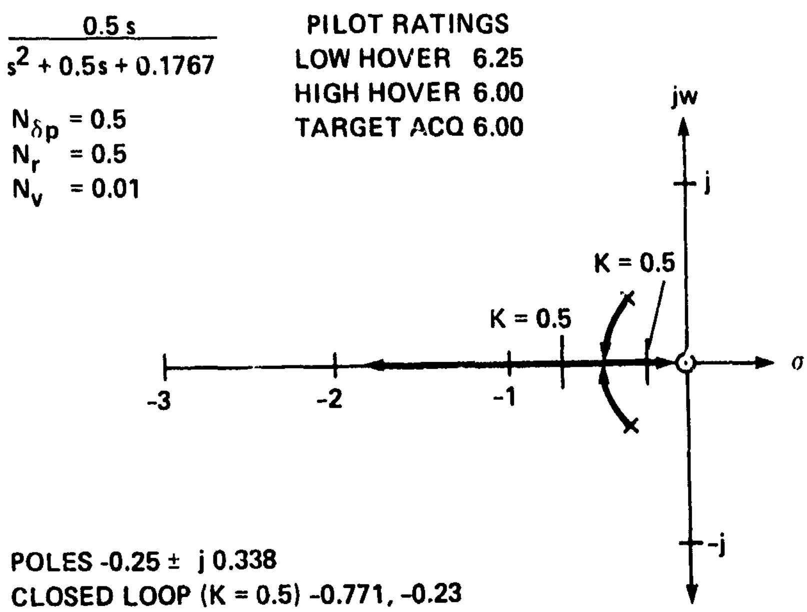


Figure I5.- Root locus plot (configuration 9).

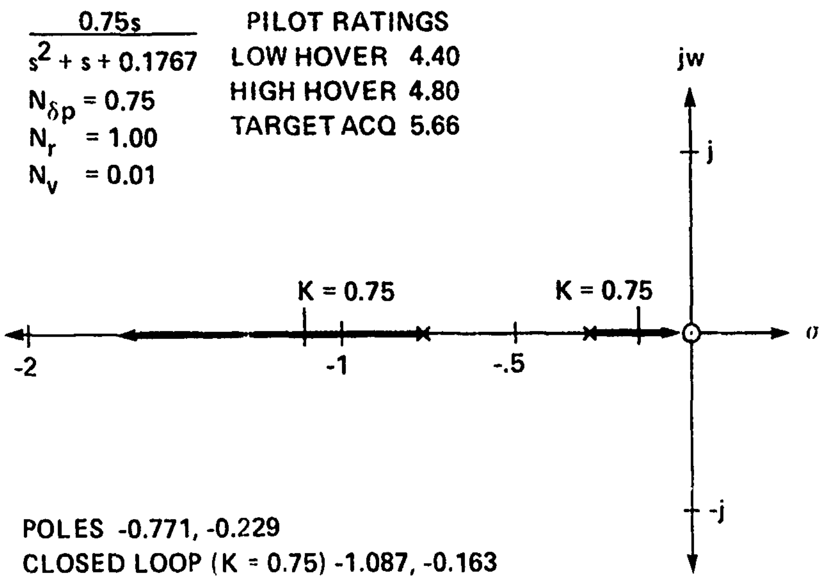


Figure I6.- Root locus plot (configuration 11).

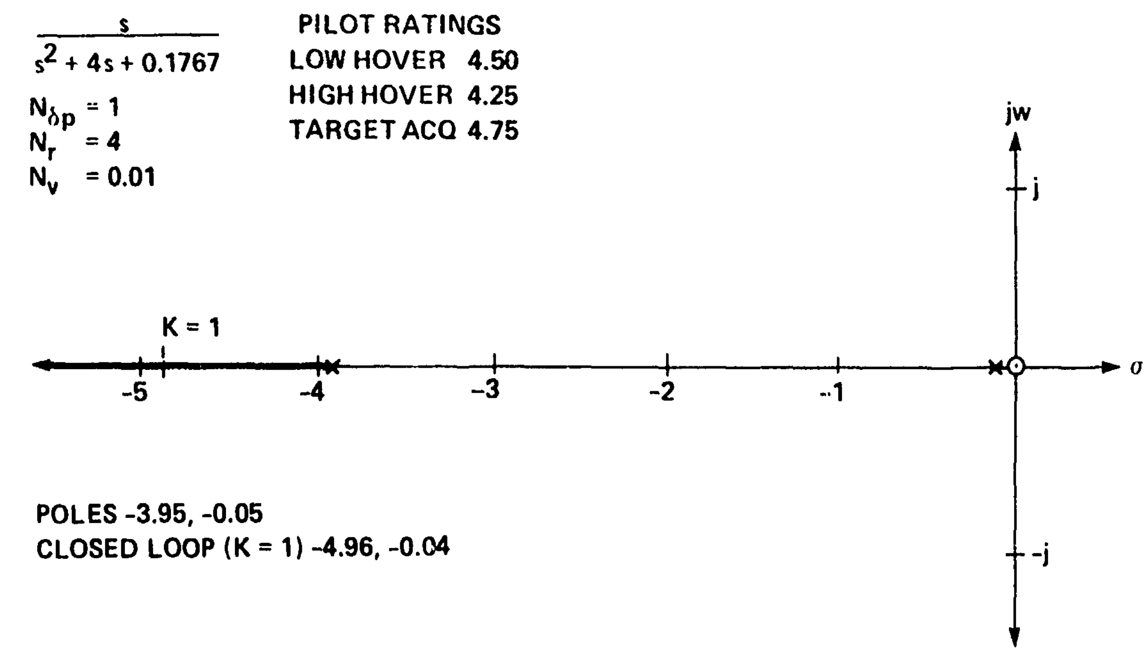


Figure I7.- Root locus plot (configuration 13).

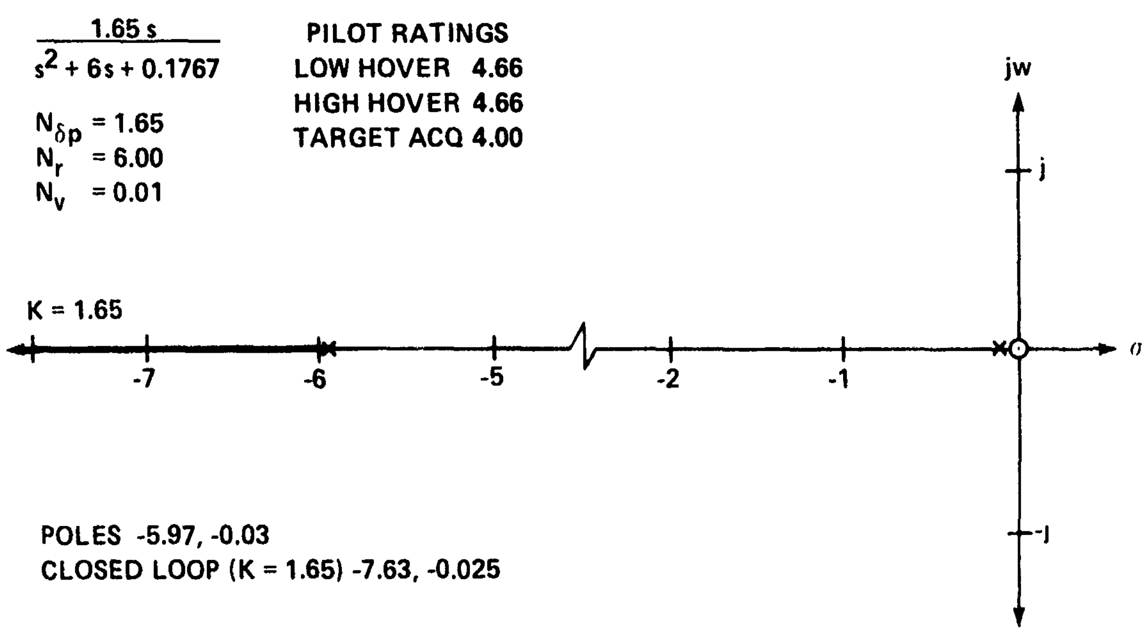


Figure I8.- Root locus plot (configuration 15).

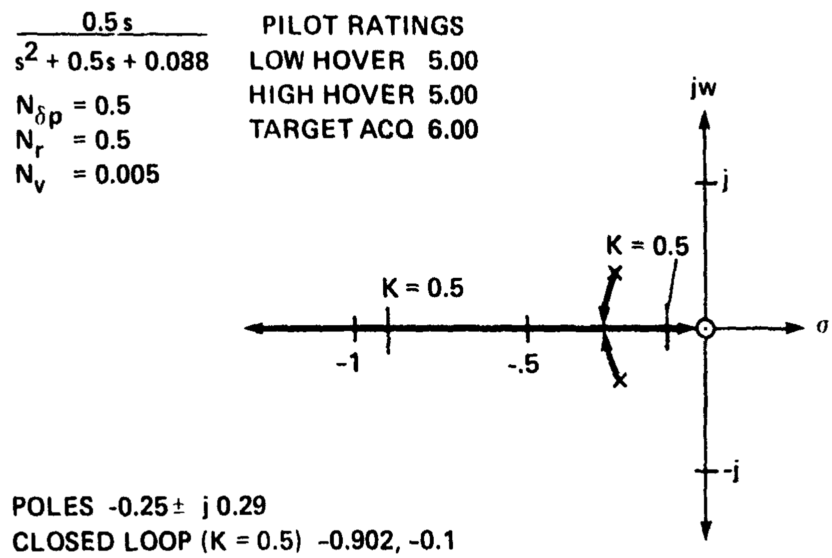


Figure I9.- Root locus plot (configuration 17).

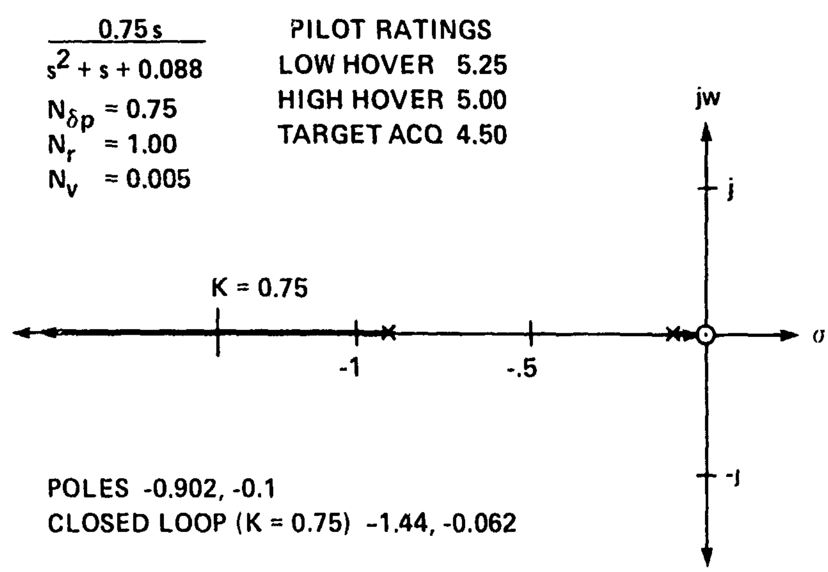


Figure I10.- Root locus plot (configuration 19).

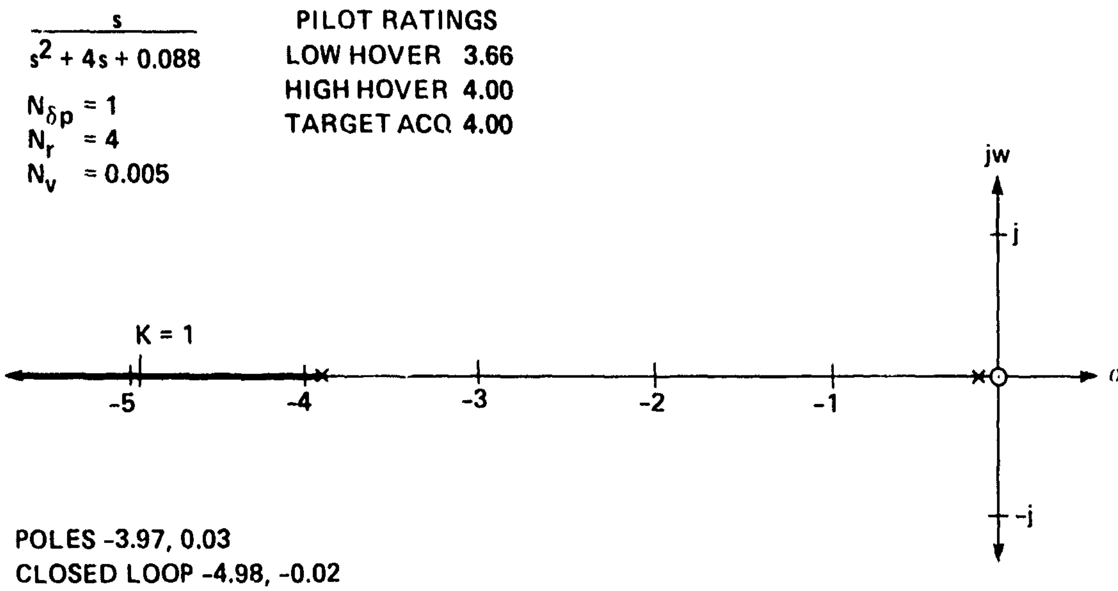


Figure I11.- Root locus plot (configuration 21).

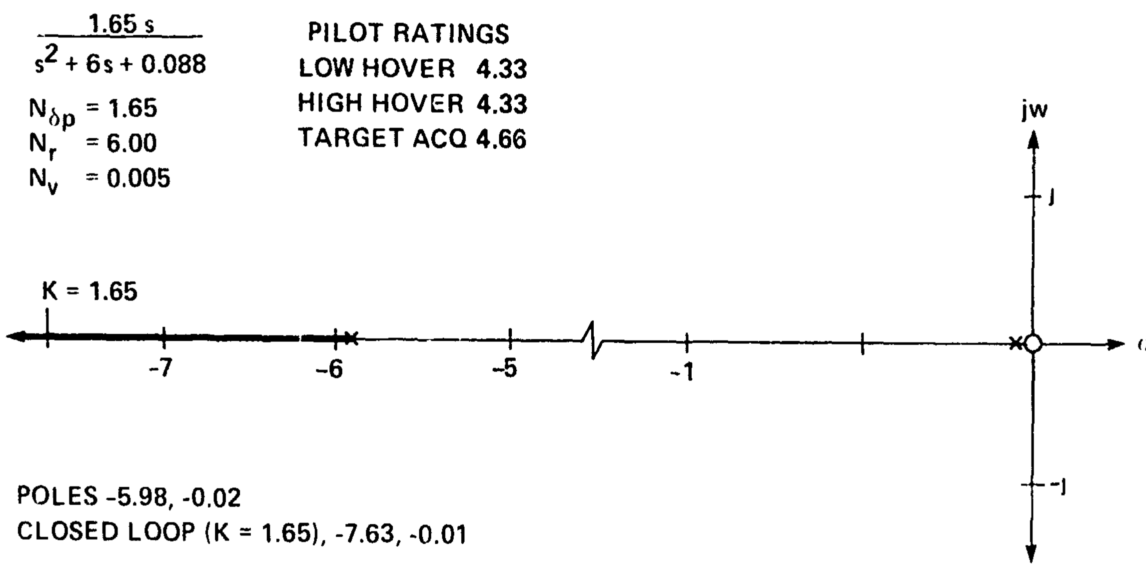


Figure I12.- Root locus plot (configuration 23).

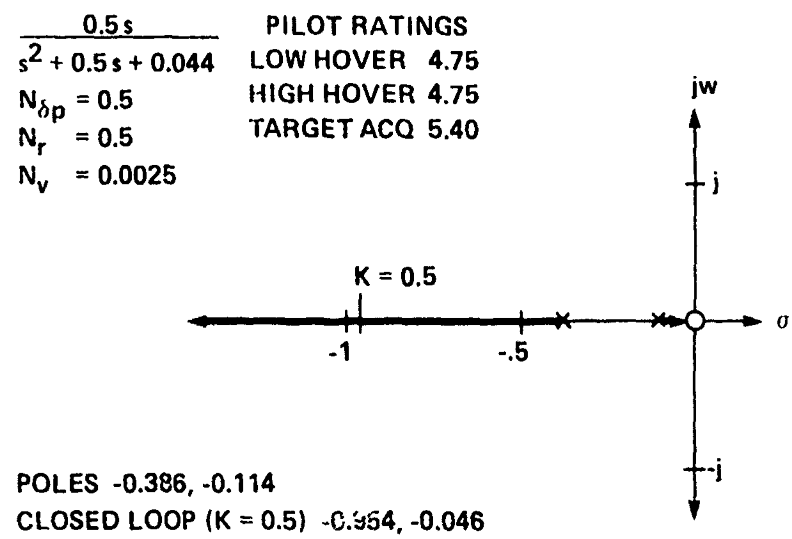


Figure I13.- Root locus plot (configuration 25).

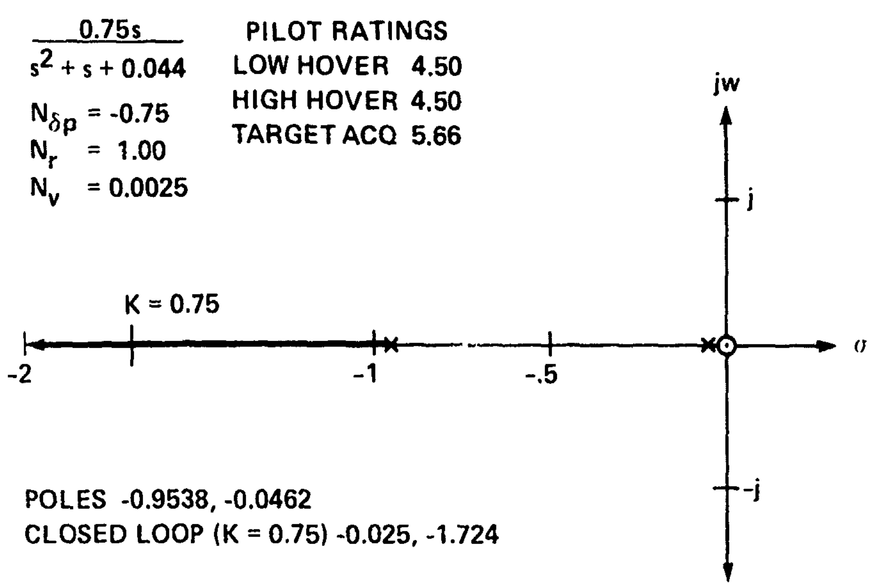


Figure I14.- Root locus plot (configuration 27).

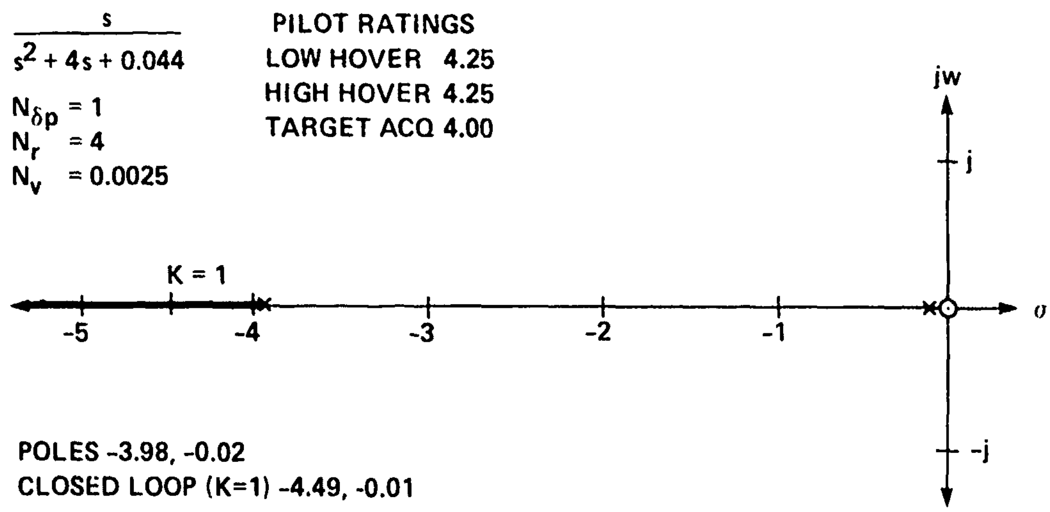


Figure I15.- Root locus plot (configuration 29).

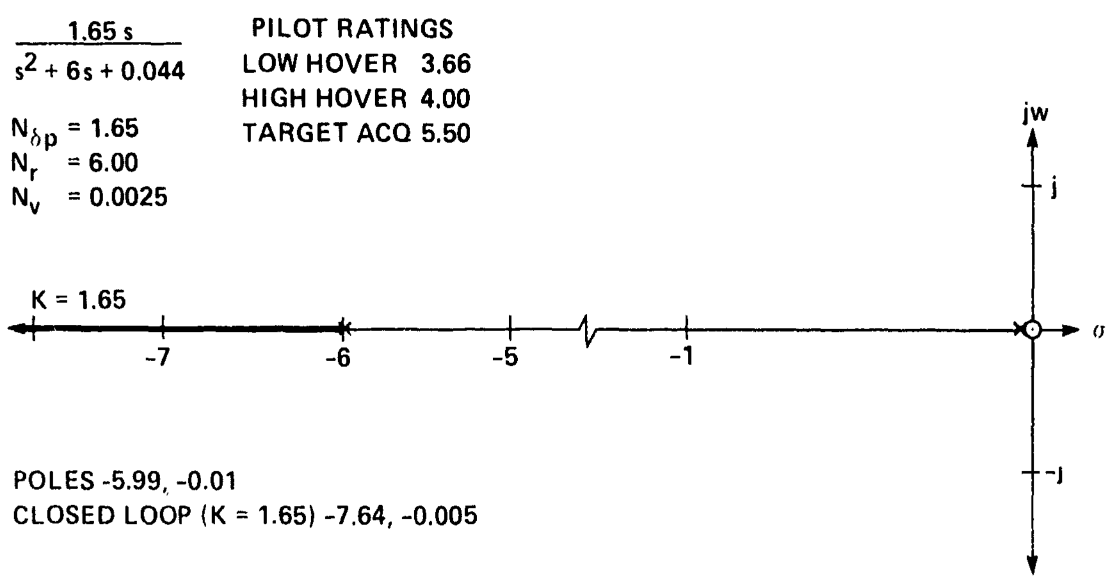


Figure I16.- Root locus plot (configuration 31).

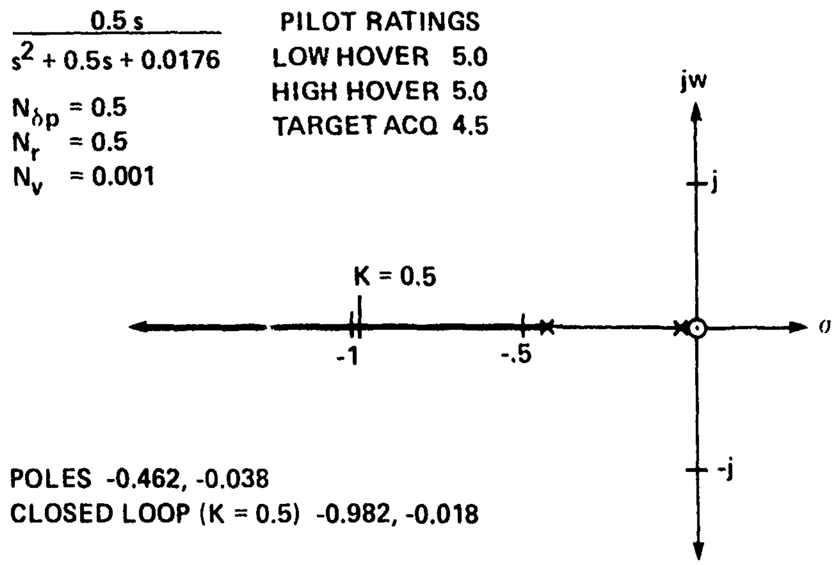


Figure I17.- Root locus plot (configuration 33).

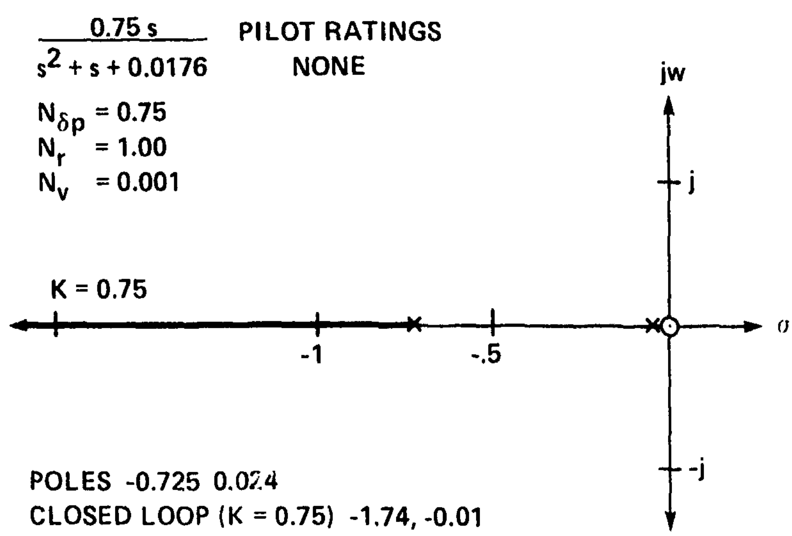


Figure I18.- Root locus plot (configuration 35).

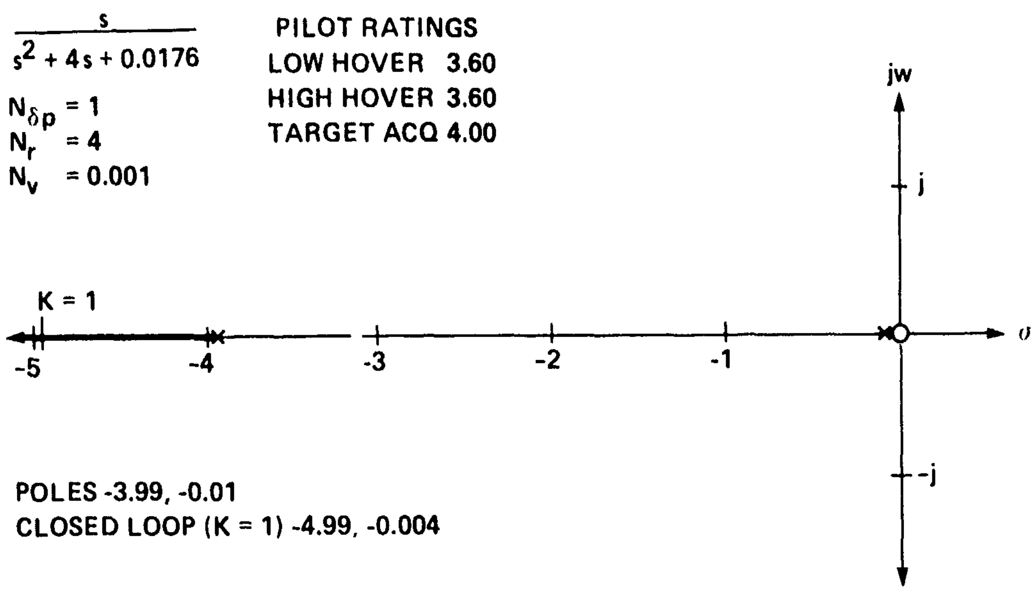


Figure I19.- Root locus plot (configuration 37).

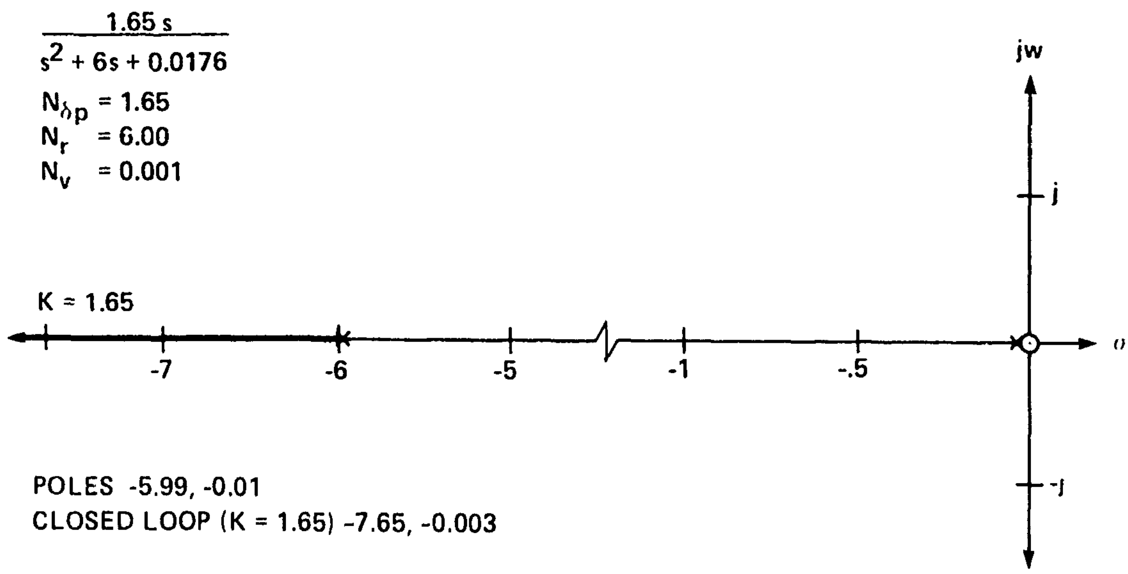


Figure I20.- Root locus plot (configuration 39).

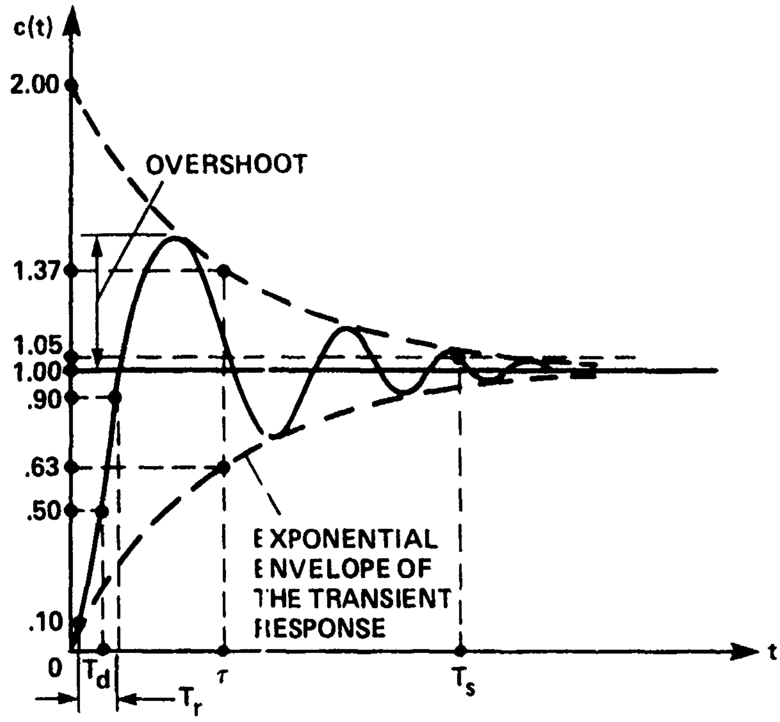


Figure I21.- Plot of unit-step response of an underdamped second-order system illustrating time-domain specification.

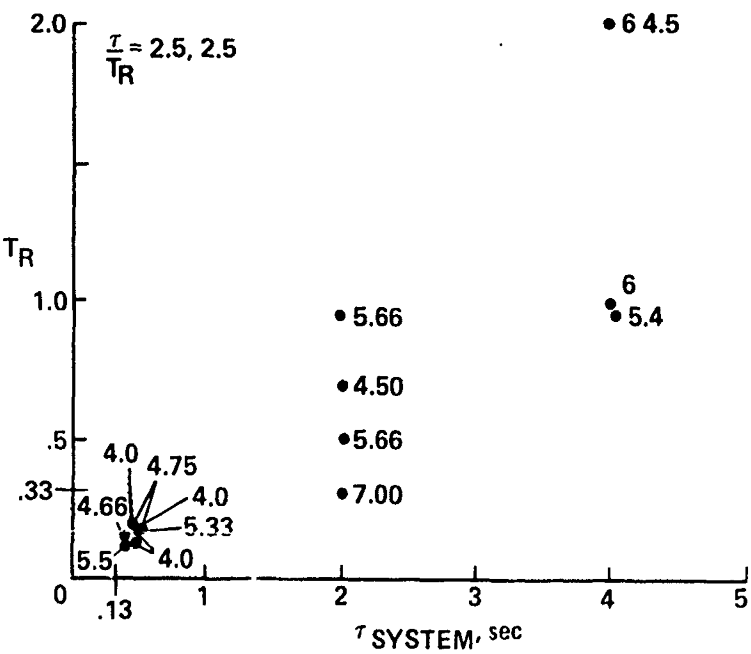


Figure I22.- Pilot ratings for rise time (T_R) vs predominant time constant (τ) -- target acquisition task.

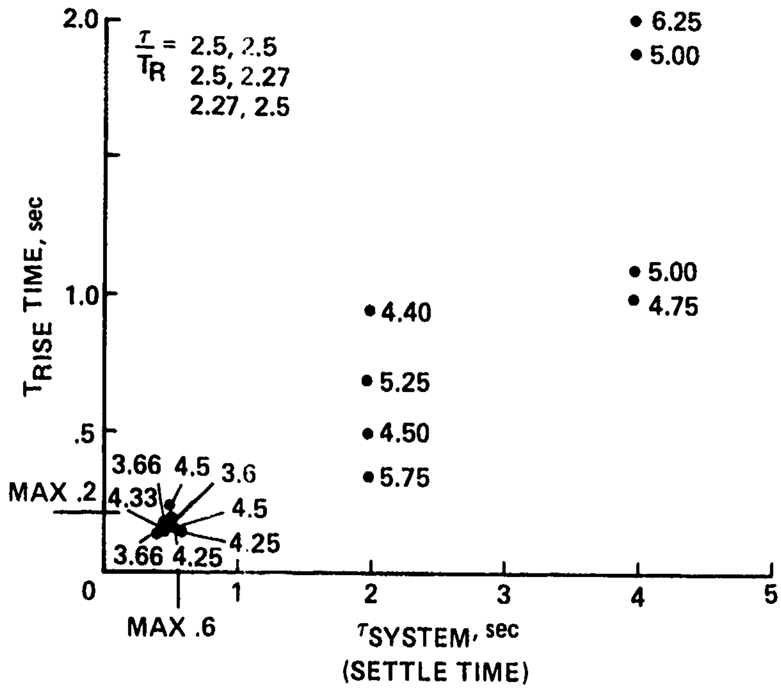


Figure I23.- Pilot ratings for rise time (T_R) vs predominant time constant (τ) - low hover turns task.

APPENDIX J

YAW CONTROL FREQUENCY RESPONSE DATA

Table J-1 lists the adjusted pilot gain $K_{\dot{\psi}}$ to give a selected phase margin (30°) at the selected crossover frequency and the derived values for open-loop and closed-loop bandwidths. Figures J1 through J38 list the open and closed loop frequency response plots for each configuration.

TABLE J-1.- YAW CONTROL CONFIGURATION FREQUENCY RESPONSE DATA

Configuration	$K_{\dot{\psi}}$	ω_{Bw} open	ω_{Bw} closed
1	5.85	0.90	2.40
3	4.07	1.26	2.45
5	4.33	4.00	3.28
7	4.03	5.42	3.65
9	5.97	.74	2.50
11	4.14	1.14	2.30
13	4.96	1.60	3.10
15	4.05	1.30	3.60
17	6.02	.64	1.30
19	4.18	1.80	2.48
21	4.98	4.00	3.19
23	4.06	5.34	3.65
25	6.05	.57	2.30
27	4.20	1.00	2.40
29	4.99	4.00	3.24
31	4.06	6.00	3.61
33	6.07	.52	2.25
35	4.21	1.05	2.32
37	5.00	4.00	3.10
39	4.06	3.65	3.50

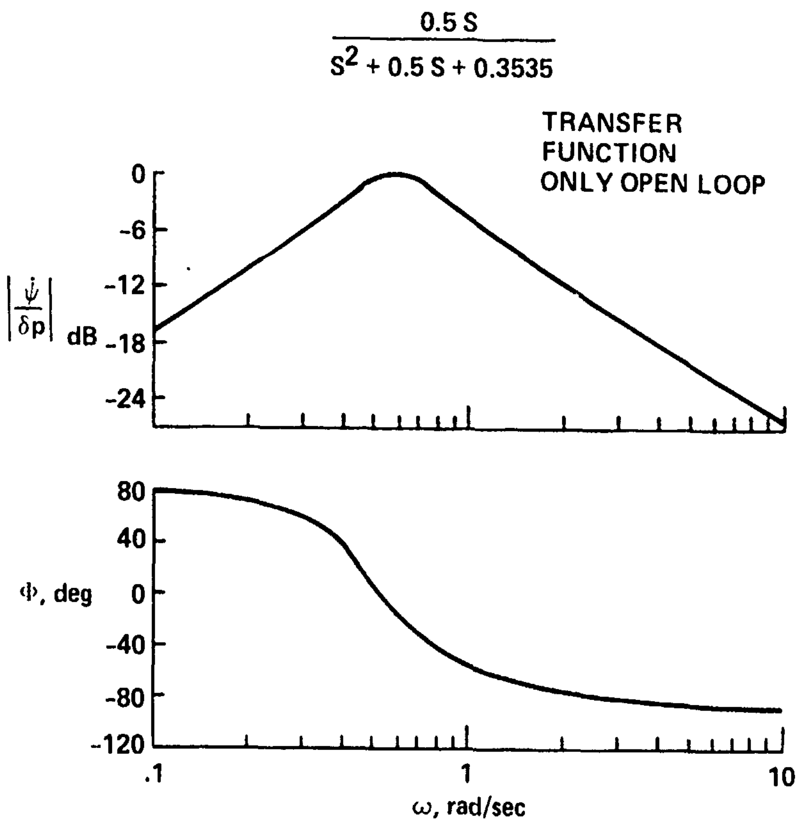


Figure J1.- Frequency response for open loop transfer function - configuration 1.

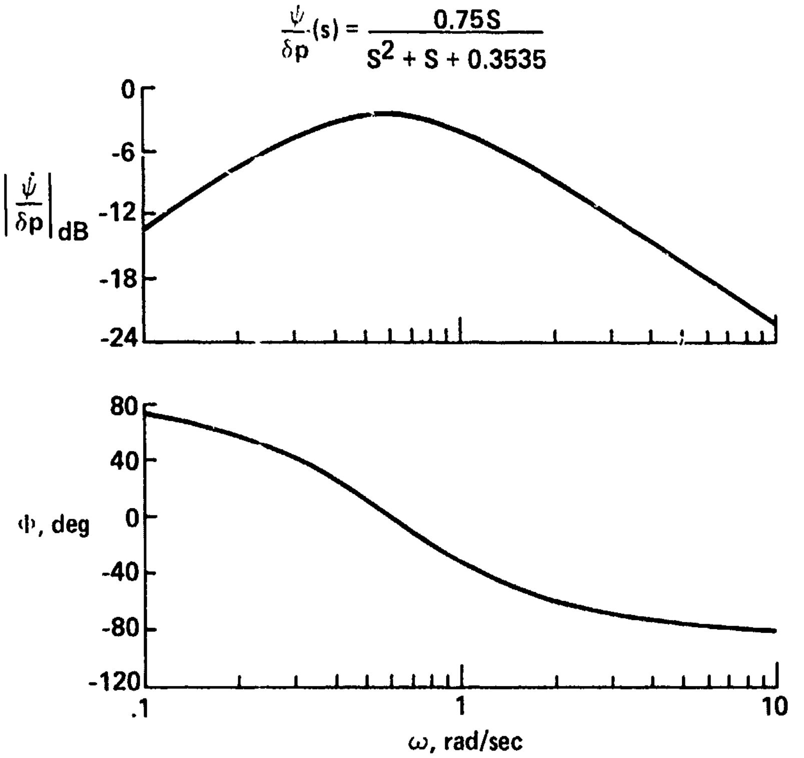


Figure J2.- Frequency response for open loop transfer function - configuration 3.

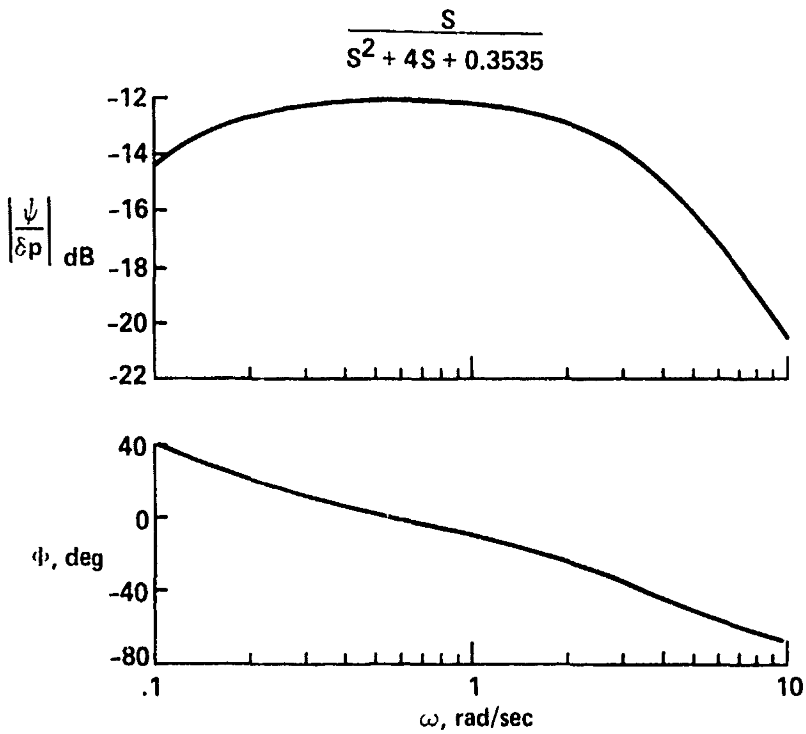


Figure J3.- Frequency response for open loop transfer function - configuration 5.

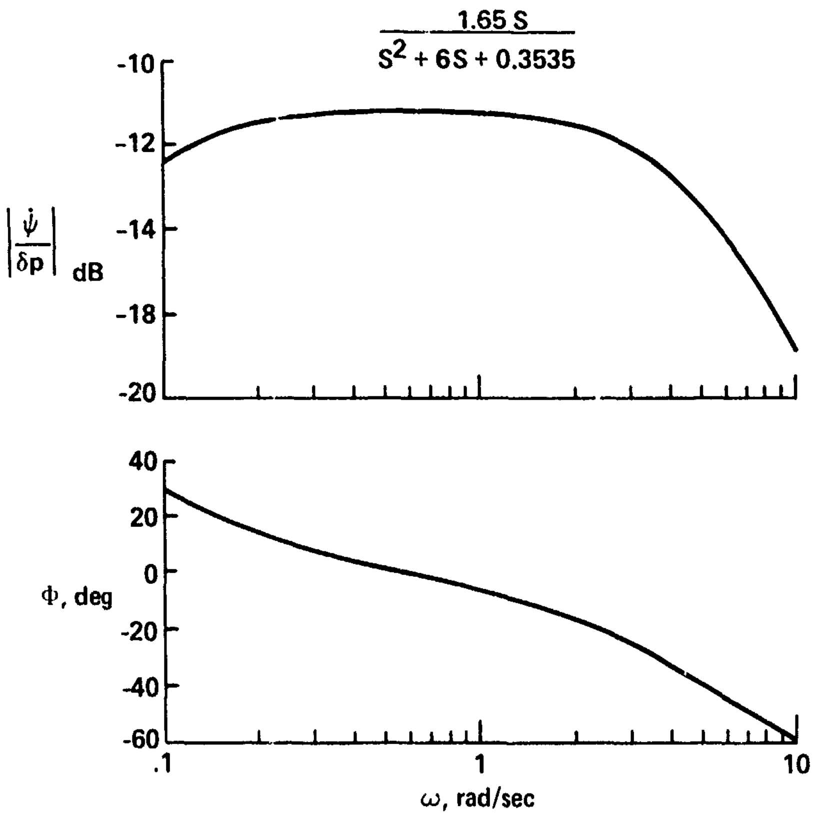


Figure J4.- Frequency response for open loop transfer function - configuration 7.

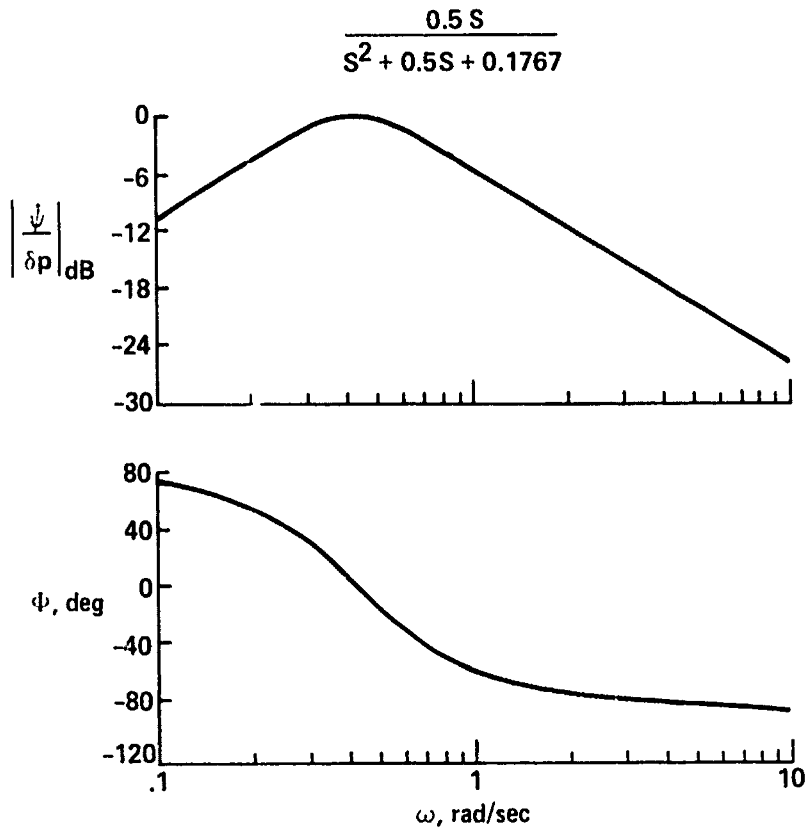


Figure J5.- Frequency response for open loop transfer function - configuration 9.

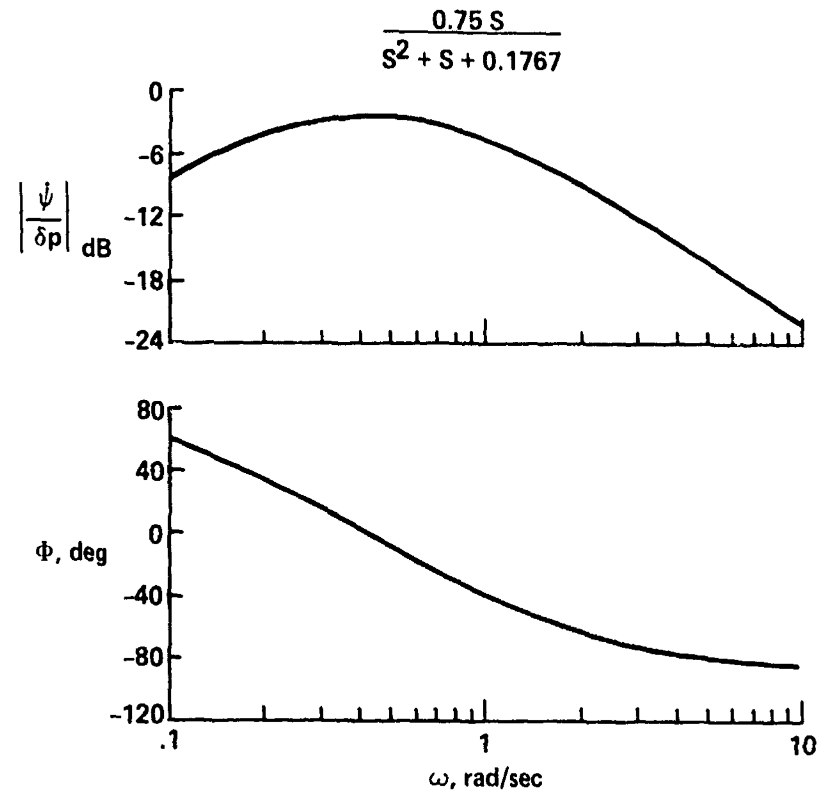


Figure J6.- Frequency response for open loop transfer function - configuration 11.

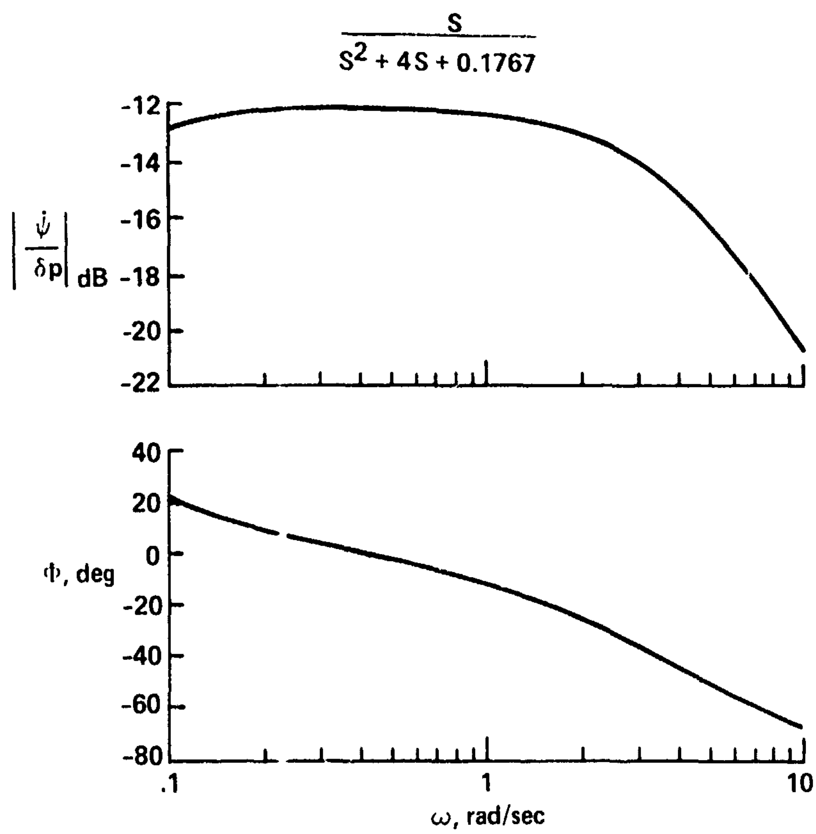


Figure J7.- Frequency response for open loop transfer function - configuration 13.

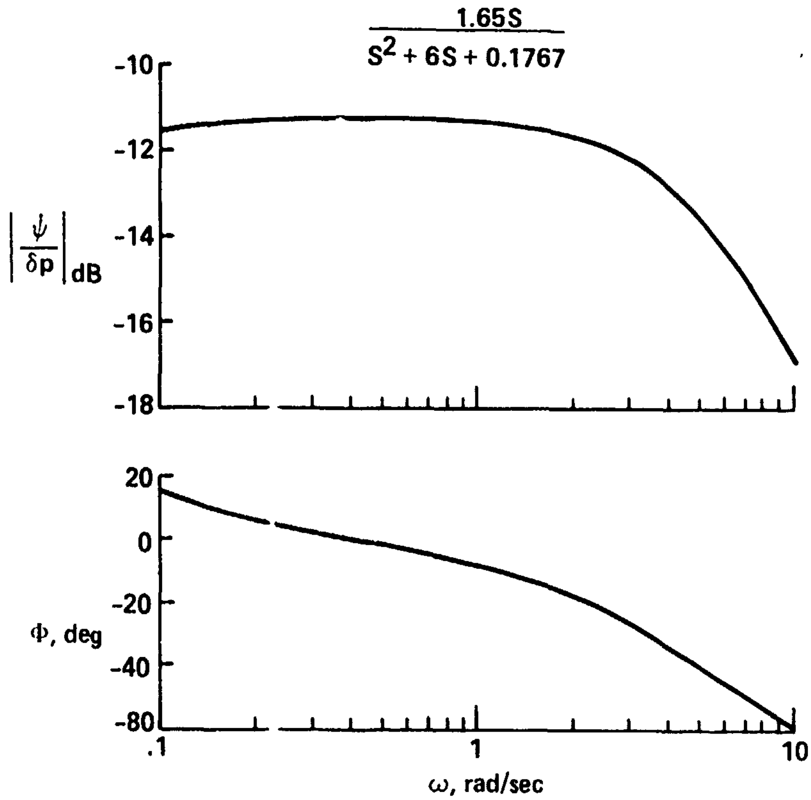


Figure J8.- Frequency response for open loop transfer function - configuration 15.

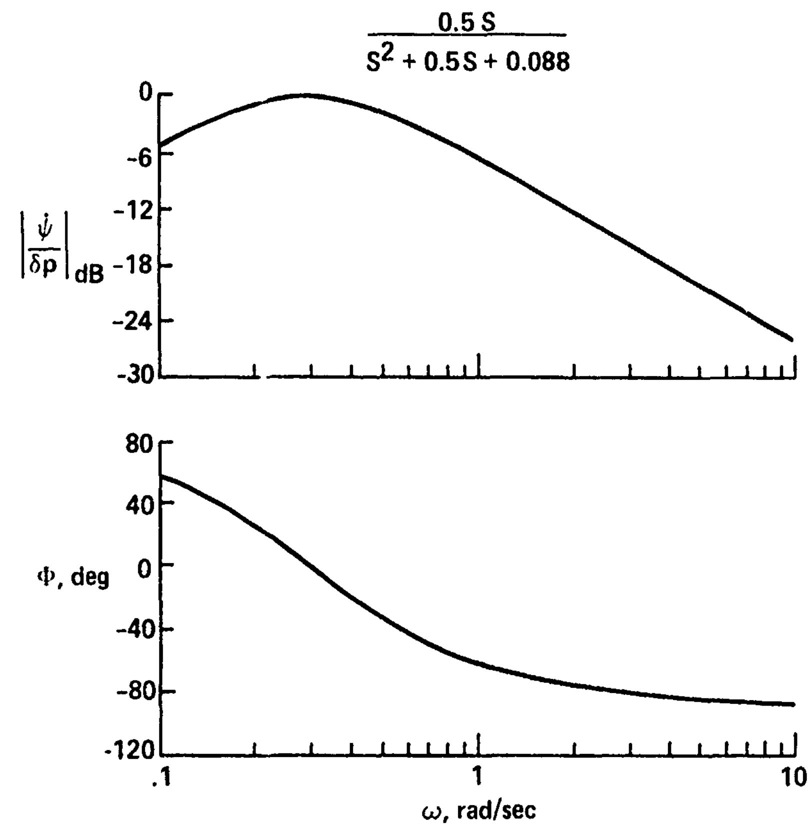


Figure J9.- Frequency response for open loop transfer function - configuration 17.

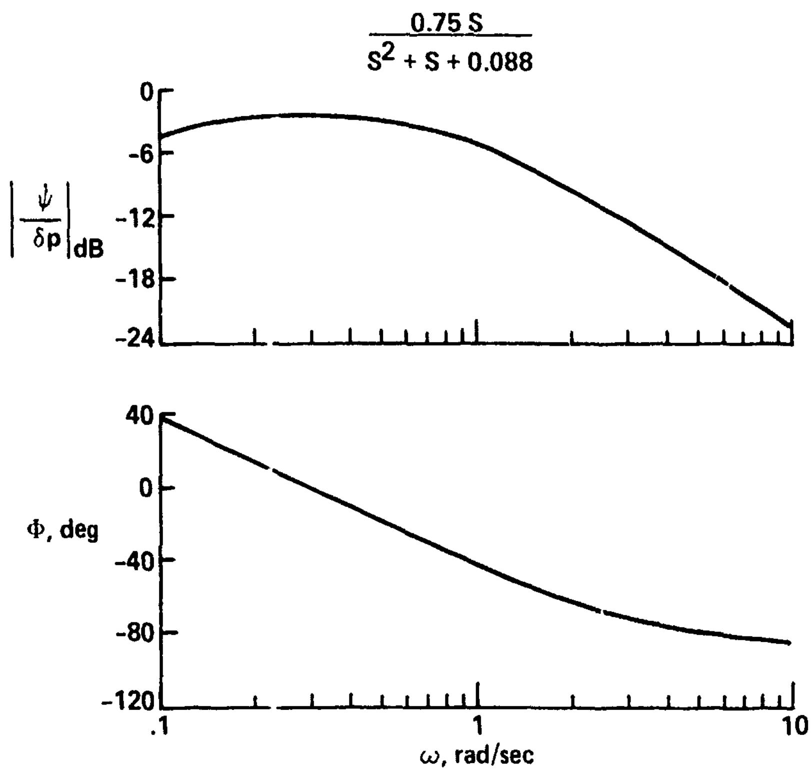


Figure J10.- Frequency response for open loop transfer function - configuration 19.

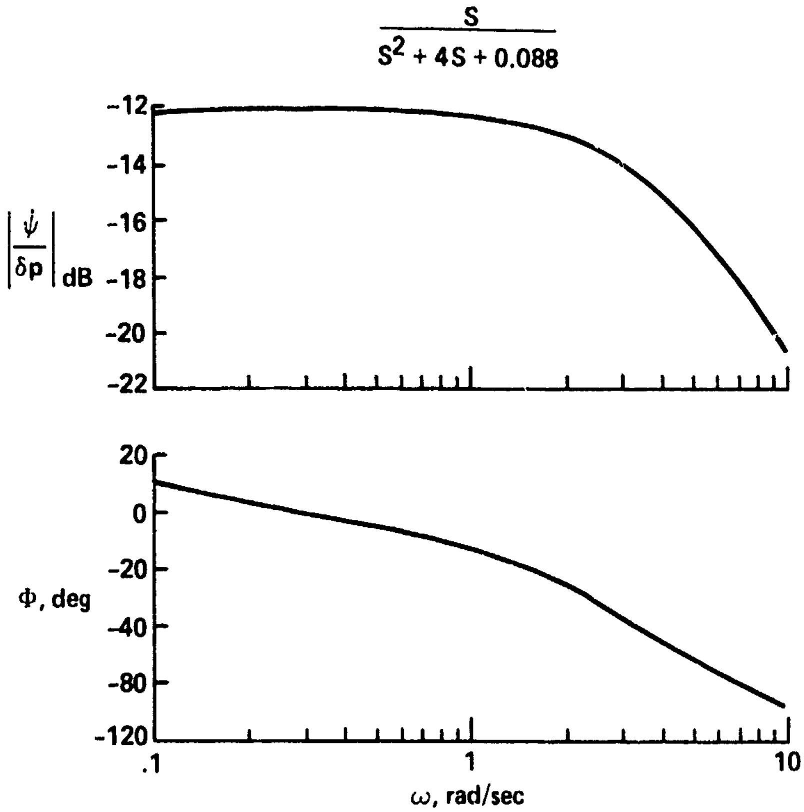


Figure J11.- Frequency response for open loop transfer function - configuration 21.

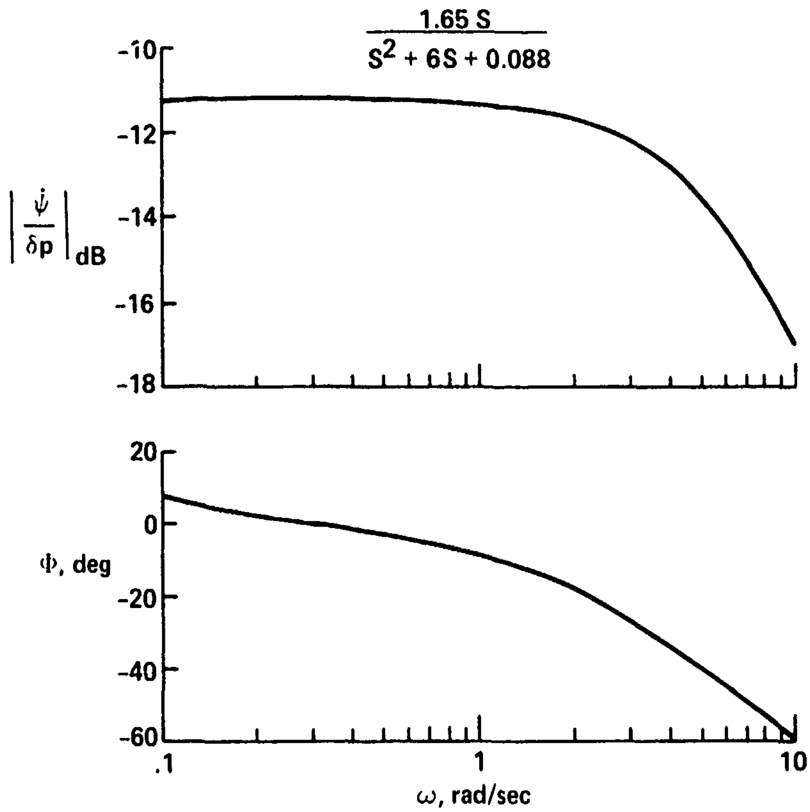


Figure J12.- Frequency response for open loop transfer function - configuration 23.

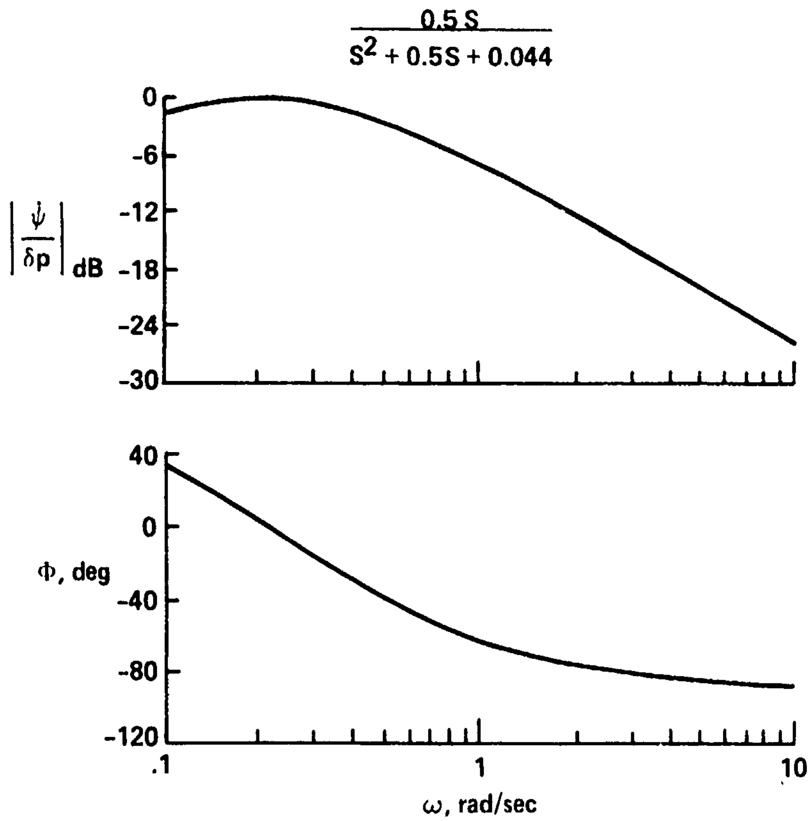


Figure J13.- Frequency response for open loop transfer function - configuration 25.

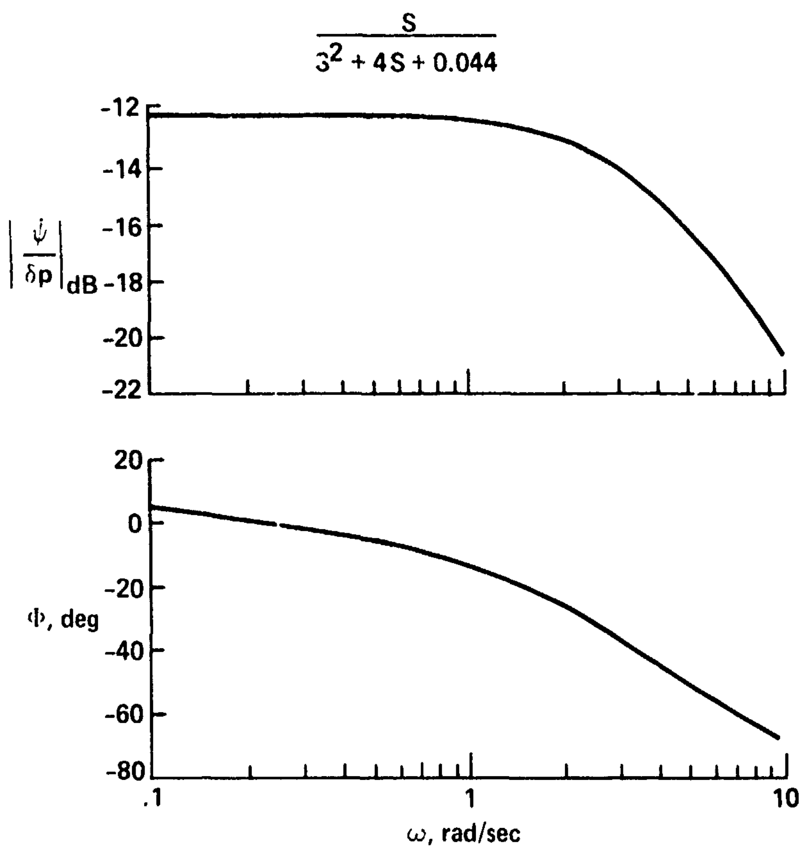


Figure J14.- Frequency response for open loop transfer function - configuration 29.

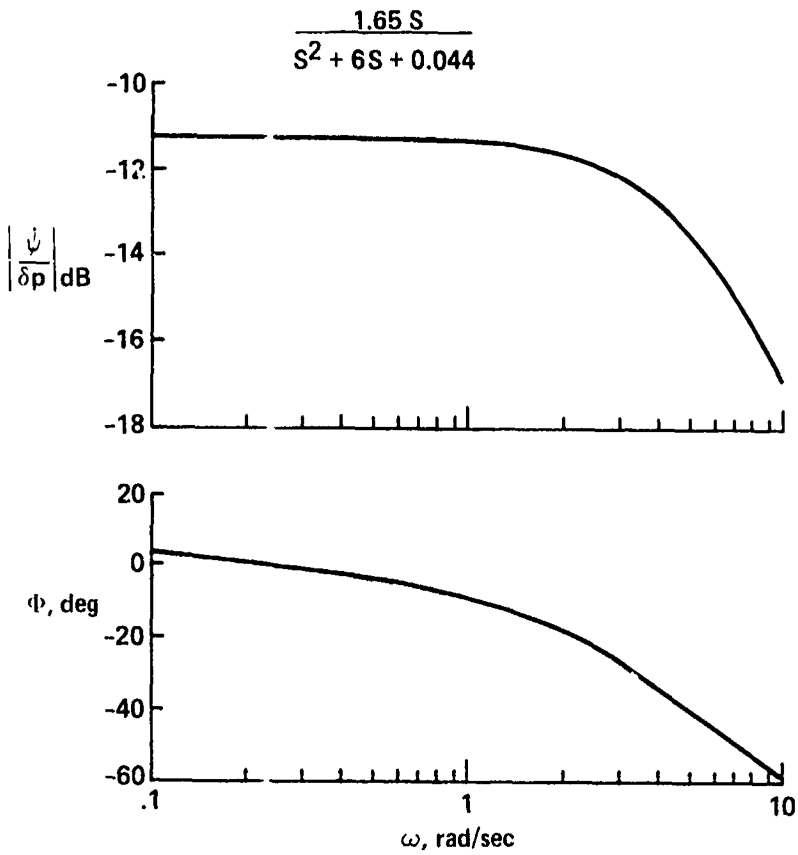


Figure J15.- Frequency response for open loop transfer function - configuration 31.

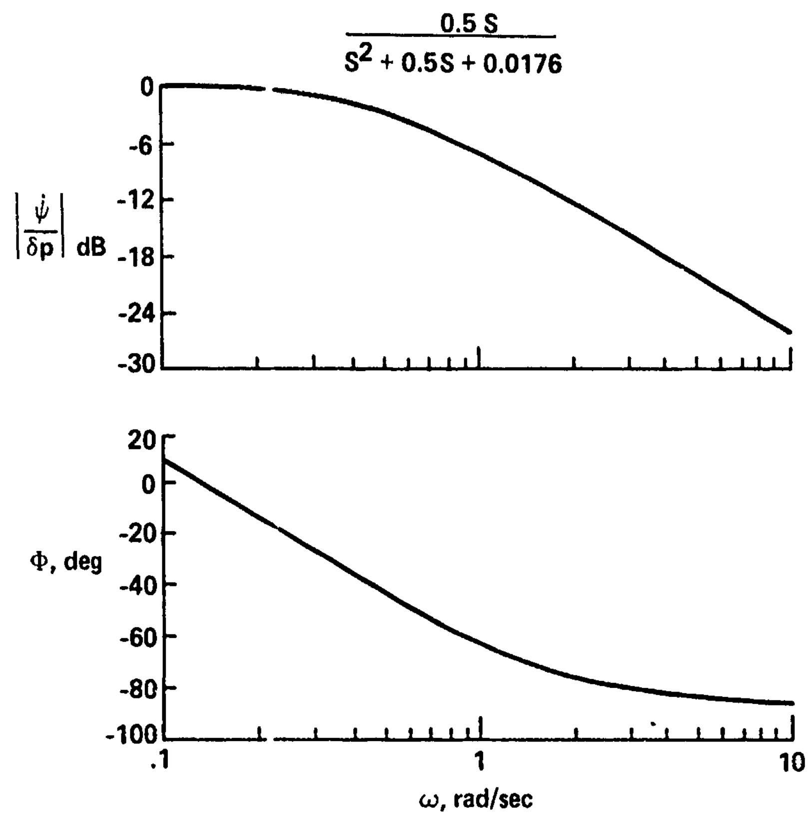


Figure J16.- Freouency response for open loop transfer function - configuration 33.

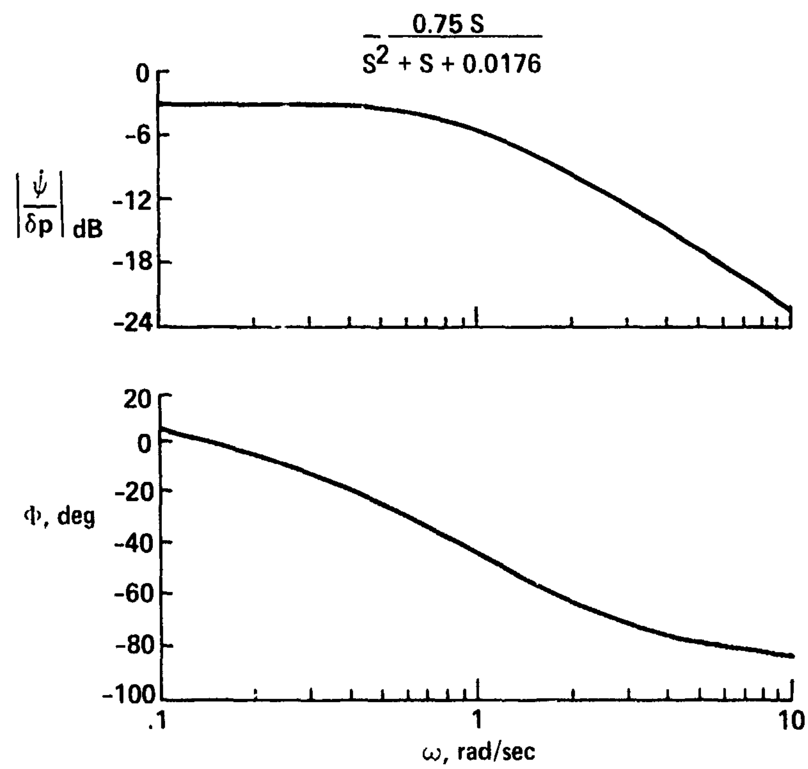


Figure J17.- Frequency response for open loop transfer function - configuration 35.

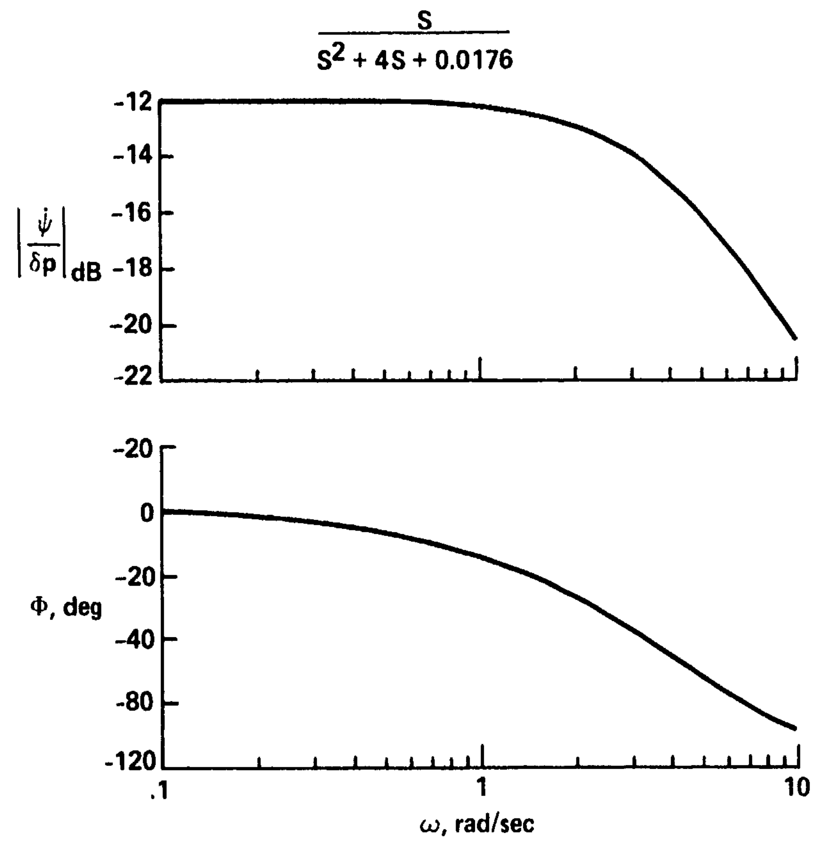


Figure J18.- Frequency response for open loop transfer function - configuration 37.

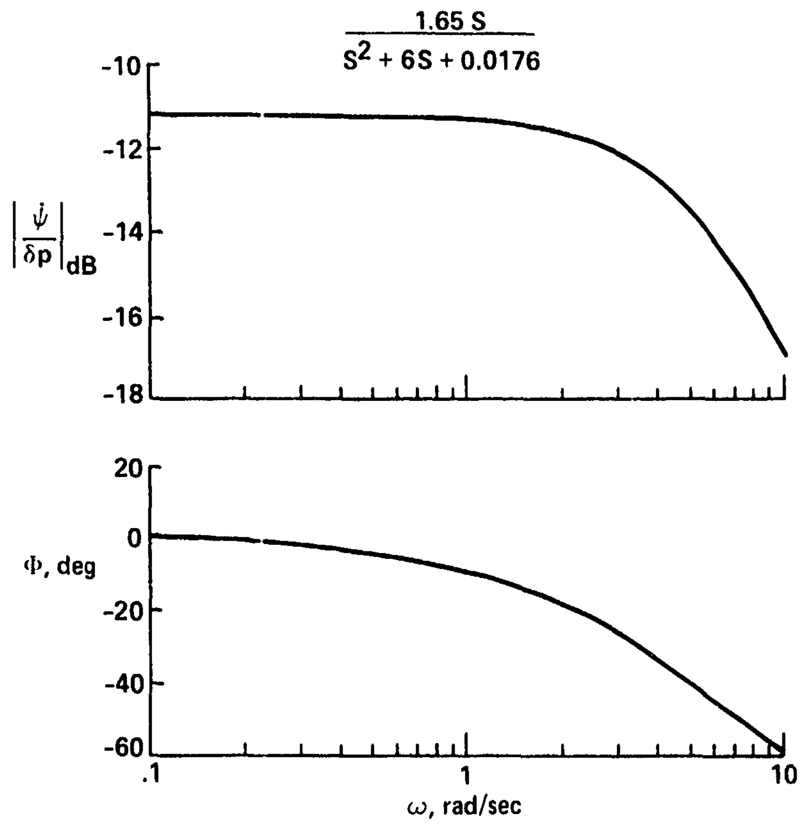


Figure J19.- Frequency response for open loop transfer function - configuration 39.

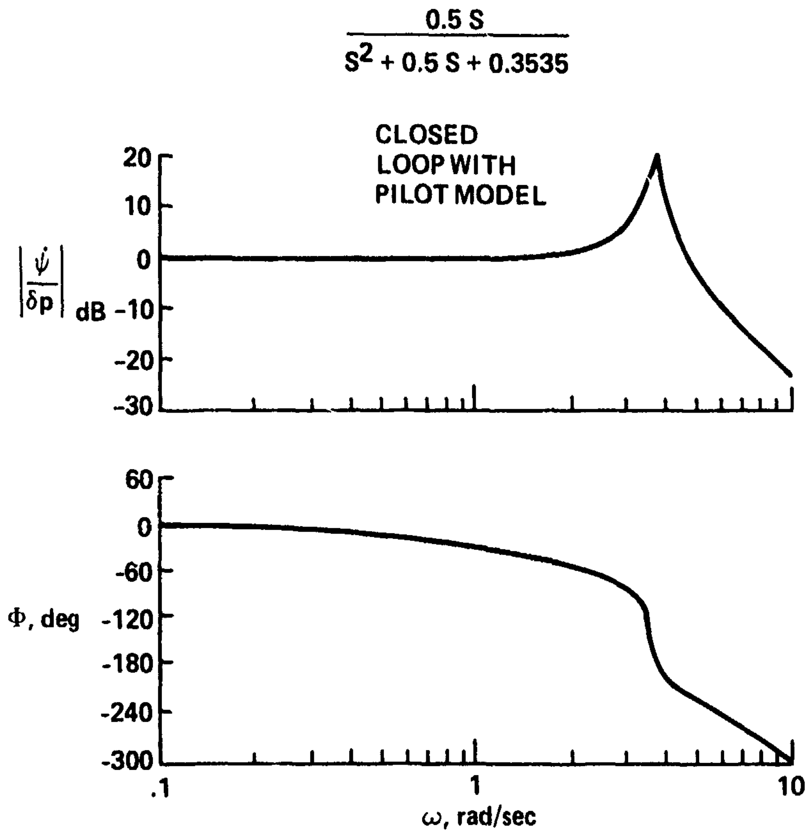


Figure J20.- Frequency response for closed loop transfer function with pilot model - configuration 1.

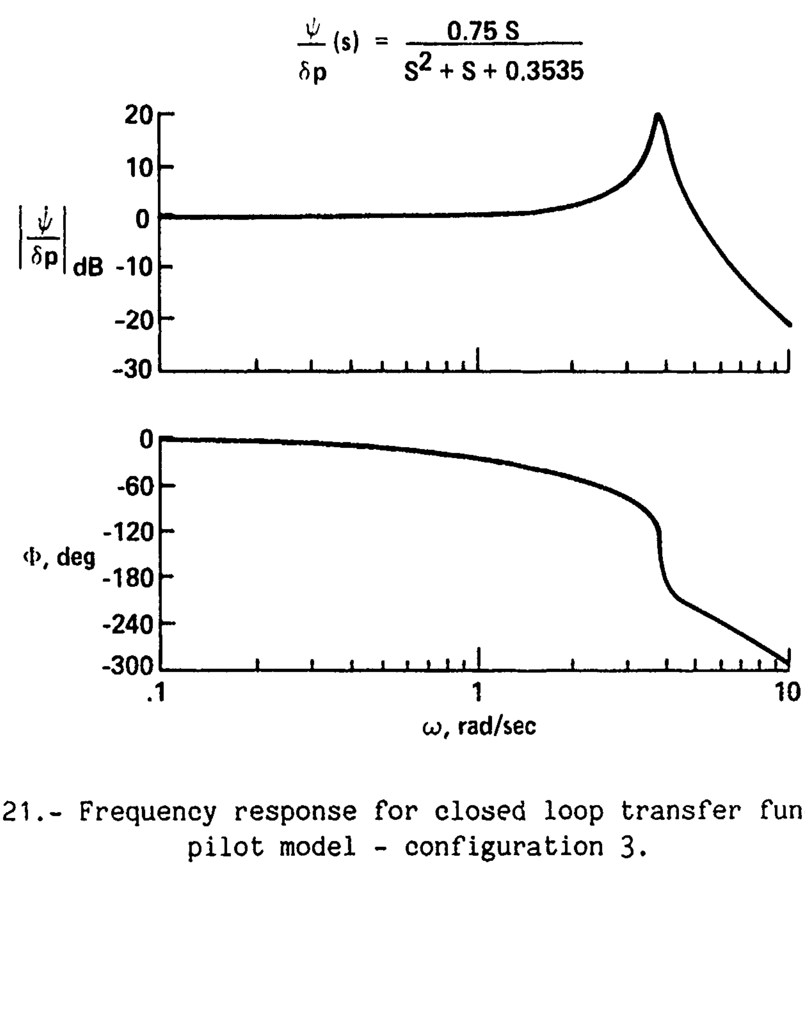


Figure J21.- Frequency response for closed loop transfer function with pilot model - configuration 3.

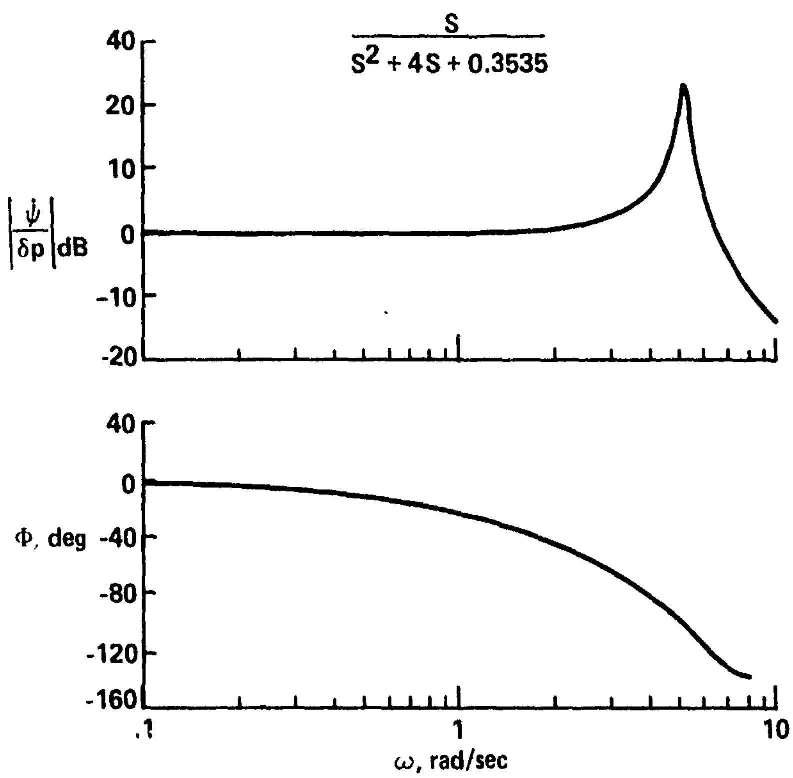


Figure J22.- Frequency response for closed loop transfer function with pilot model - configuration 5.

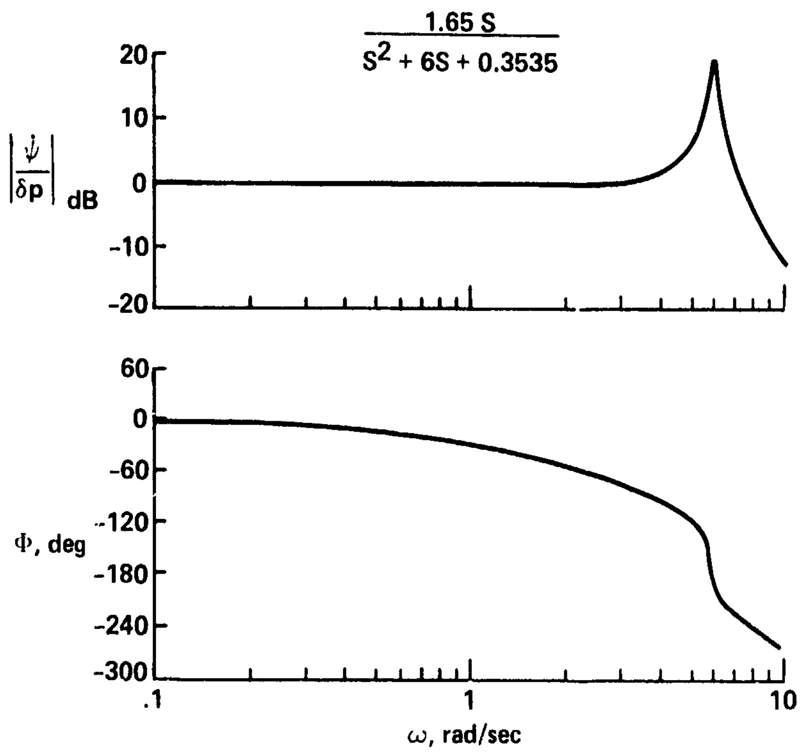


Figure J23.- Frequency response for closed loop transfer function with pilot model - configuration 7.

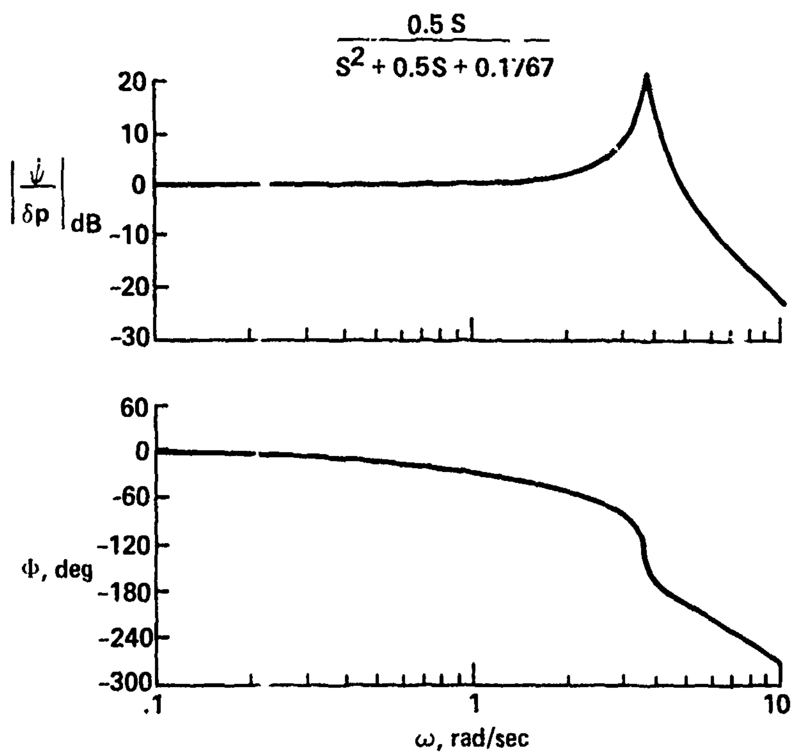


Figure J24.- Frequency response for closed loop transfer function with pilot model - configuration 9.

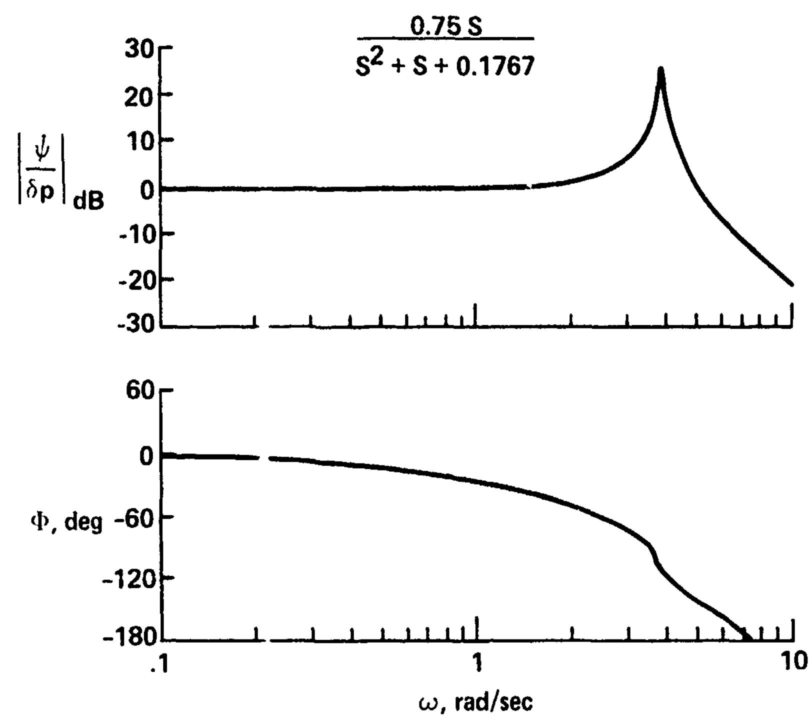


Figure J25.- Frequency response for closed loop transfer function with pilot model - configuration 11.

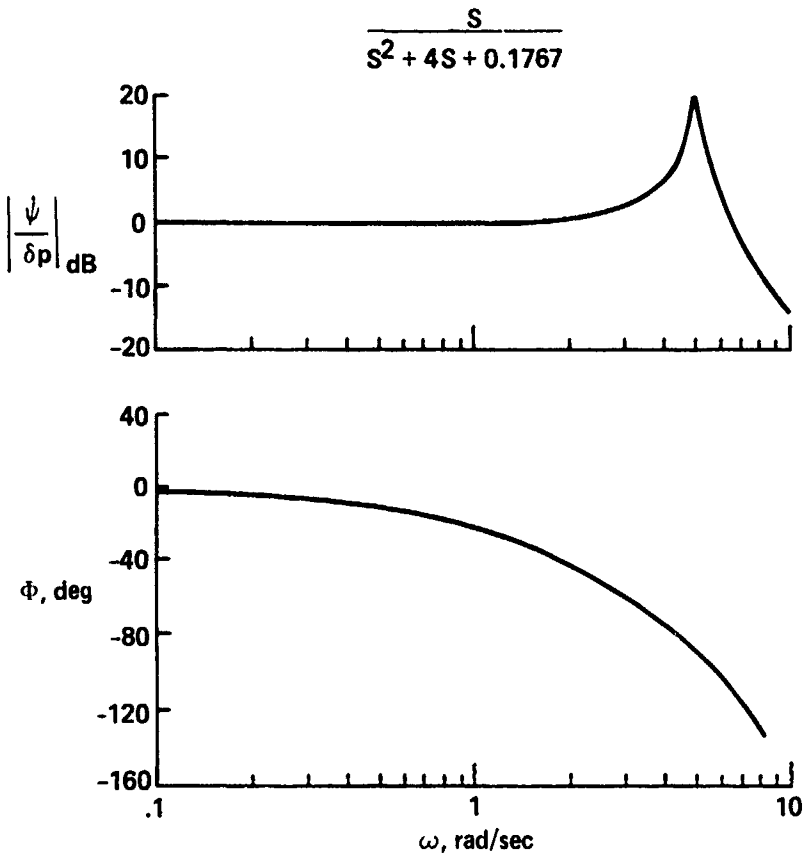


Figure J26.- Frequency response for closed loop transfer function with pilot model - configuration 13.

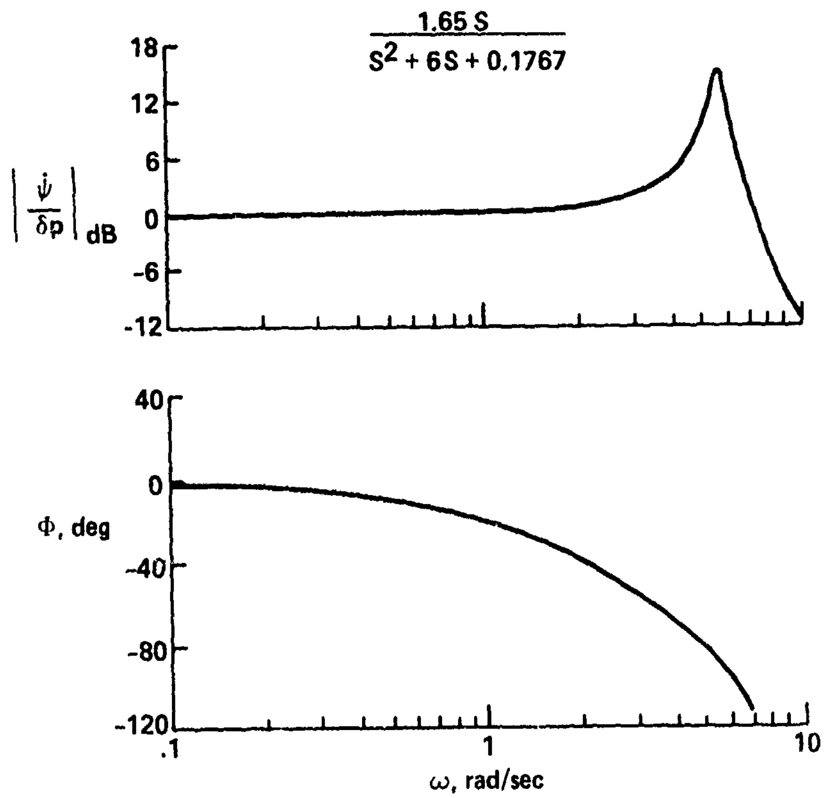


Figure J27.- Frequency response for closed loop transfer function with pilot model - configuration 15.

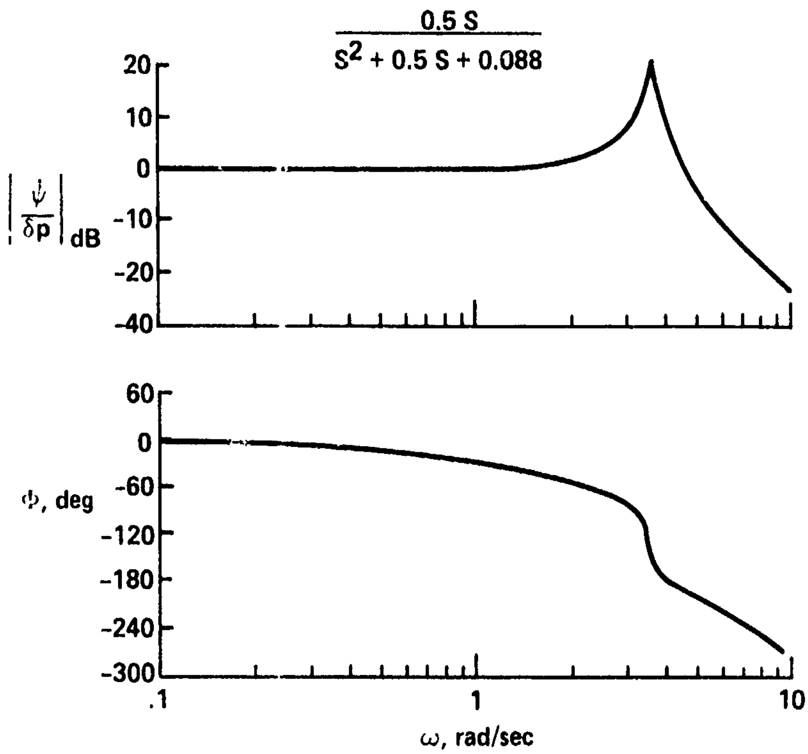


Figure J28.- Frequency response for closed loop transfer function with pilot model - configuration 17.

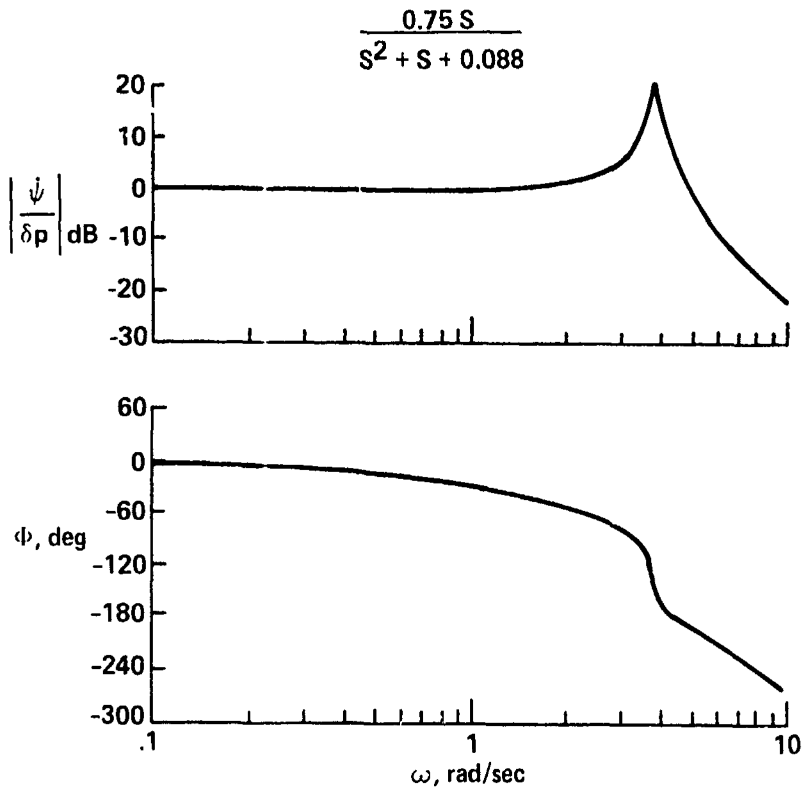


Figure J29.- Frequency response for closed loop transfer function with pilot model - configuration 19.

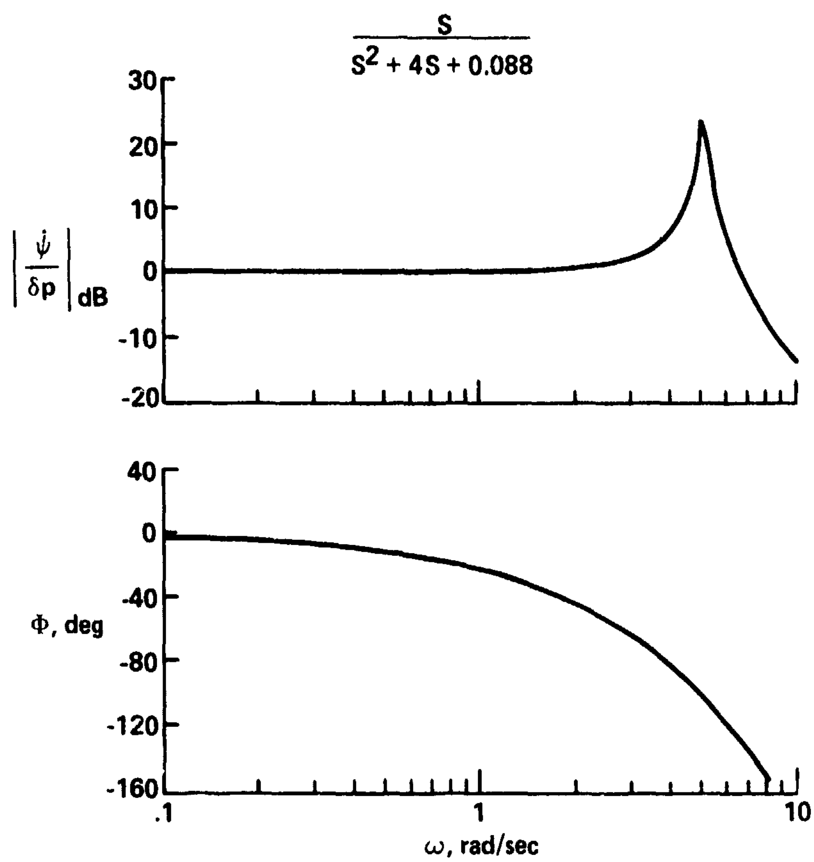


Figure J30.- Frequency response for closed loop transfer function with pilot model - configuration 21.

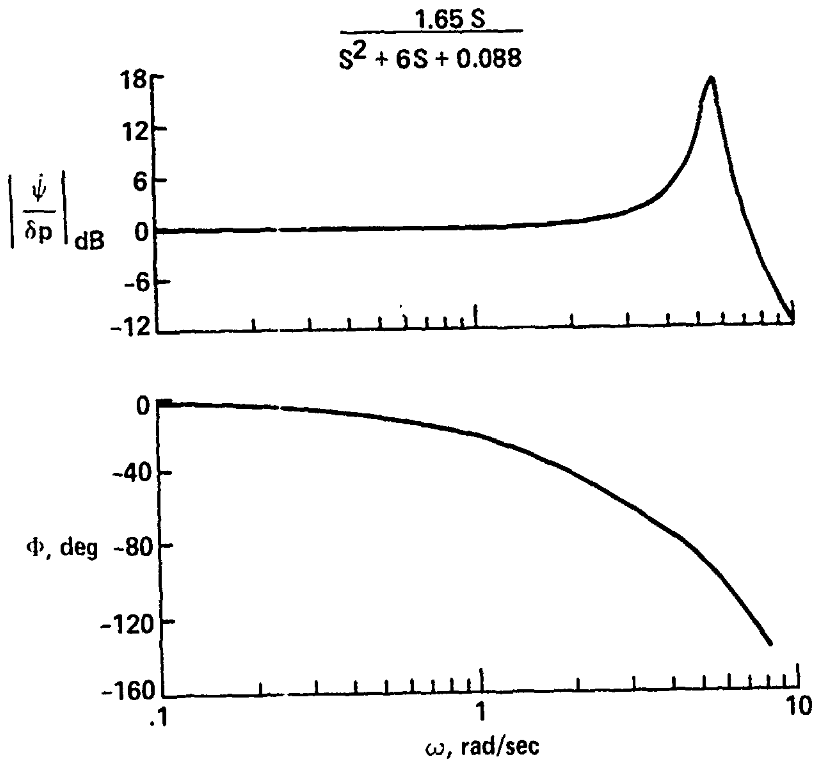


Figure J31.- Frequency response for closed loop transfer function with pilot model - configuration 23.

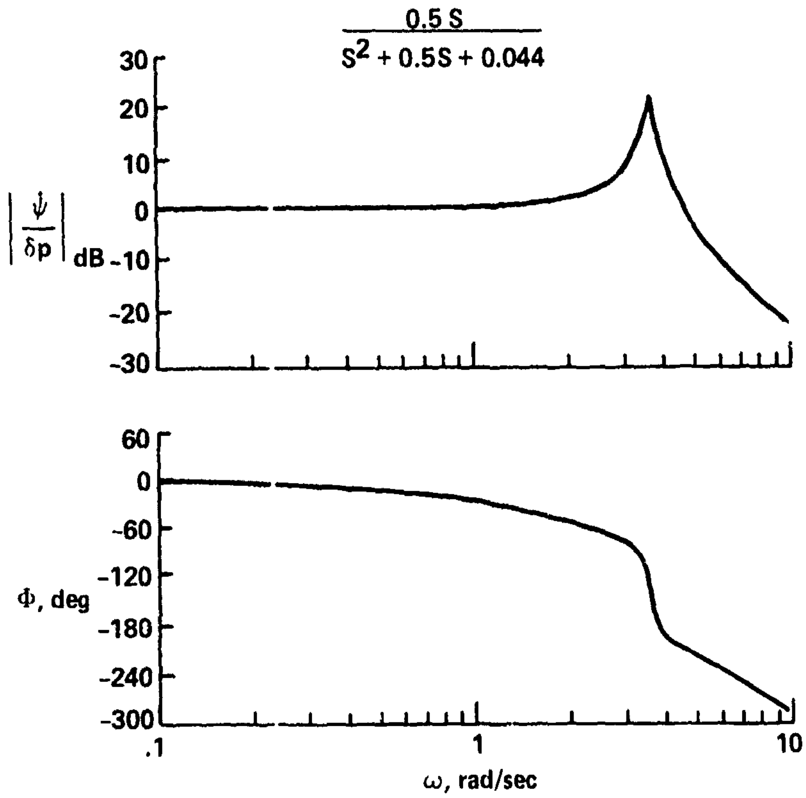


Figure J32.- Frequency response for closed loop transfer function with pilot model - configuration 25.

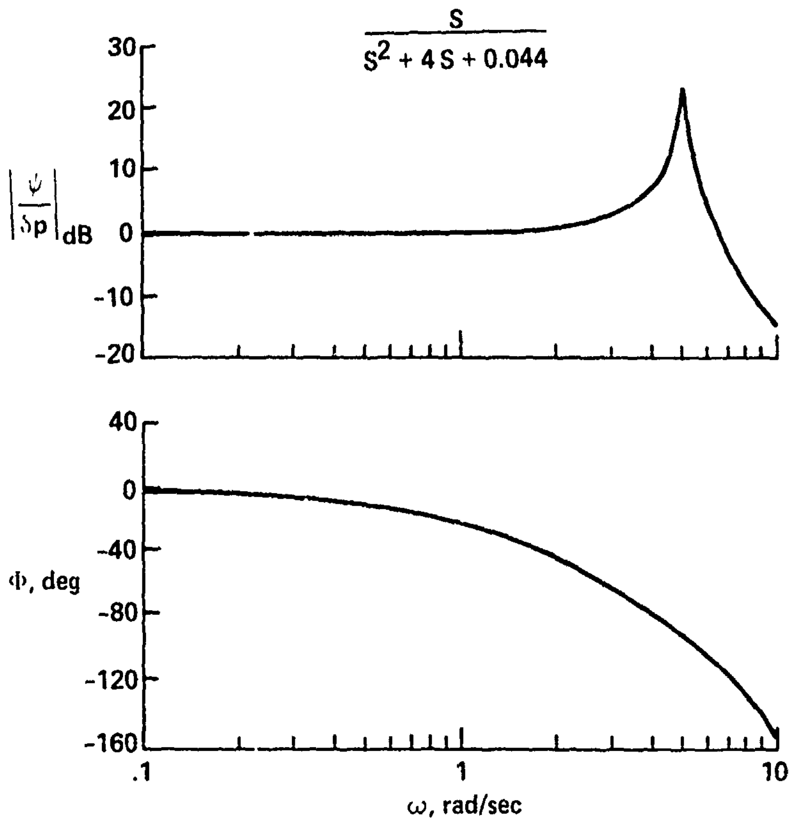


Figure J33.- Frequency response for closed loop transfer function with pilot model - configuration 27.

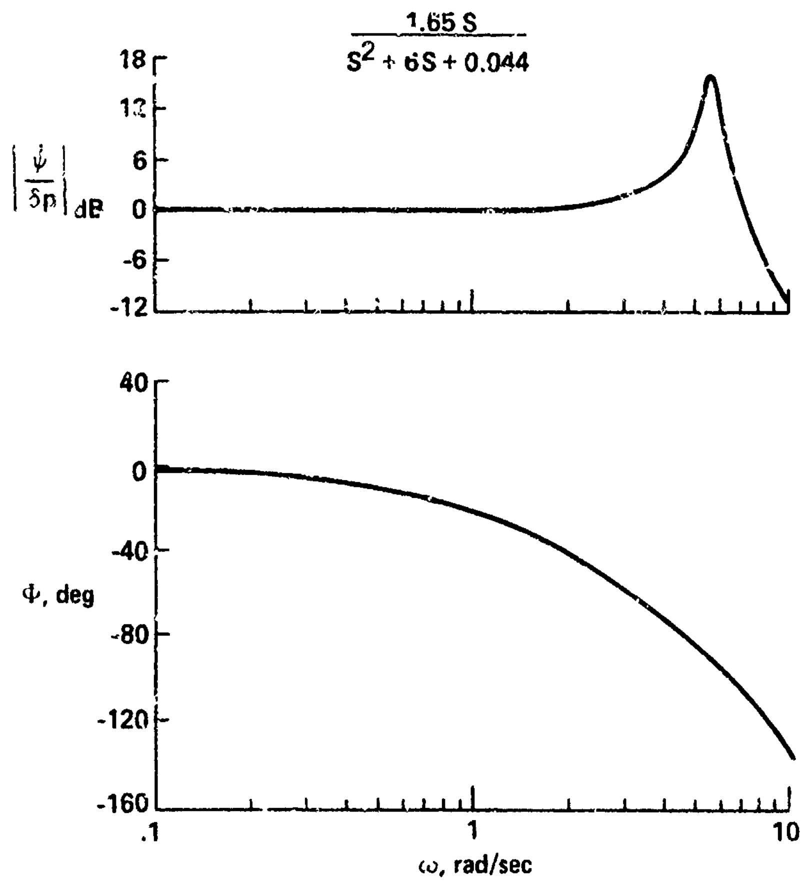


Figure J34.- Frequency response for closed loop transfer function with pilot model - configuration 29.

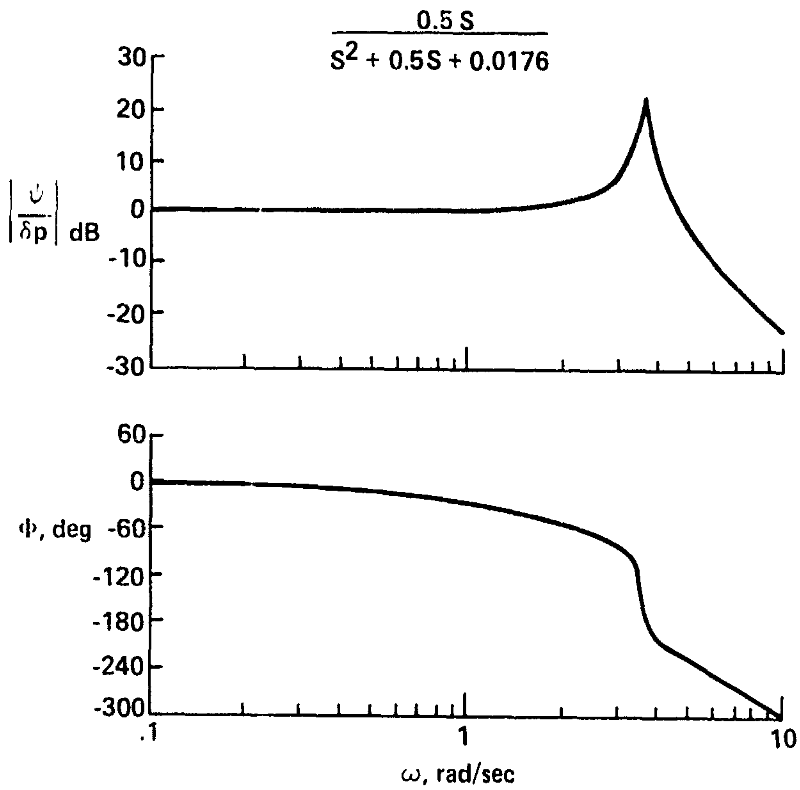


Figure J35.- Frequency response for closed loop transfer function with pilot model - configuration 31.

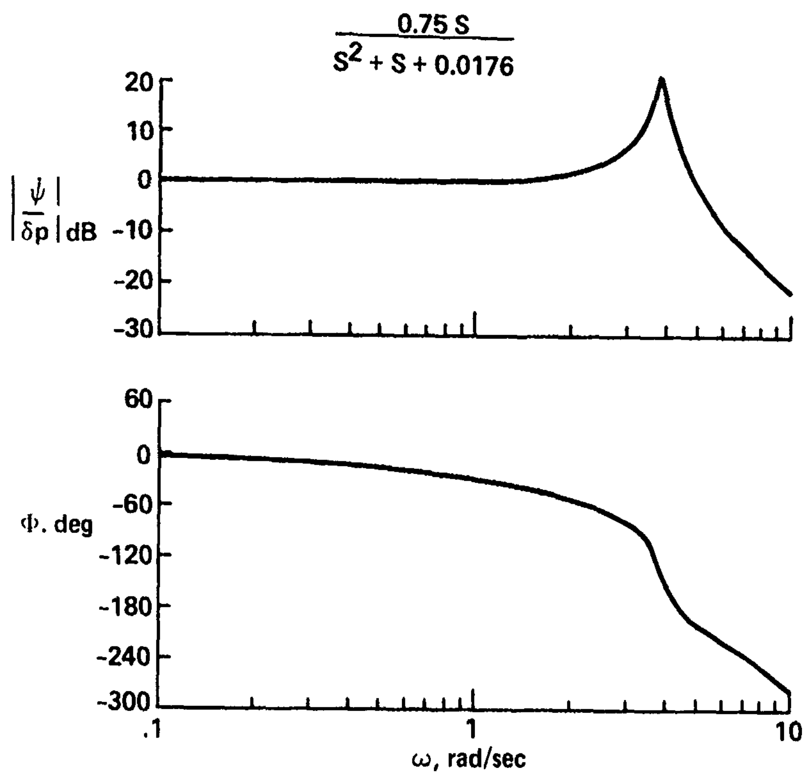


Figure J36.- Frequency response for closed loop transfer function with pilot model - configuration 33.

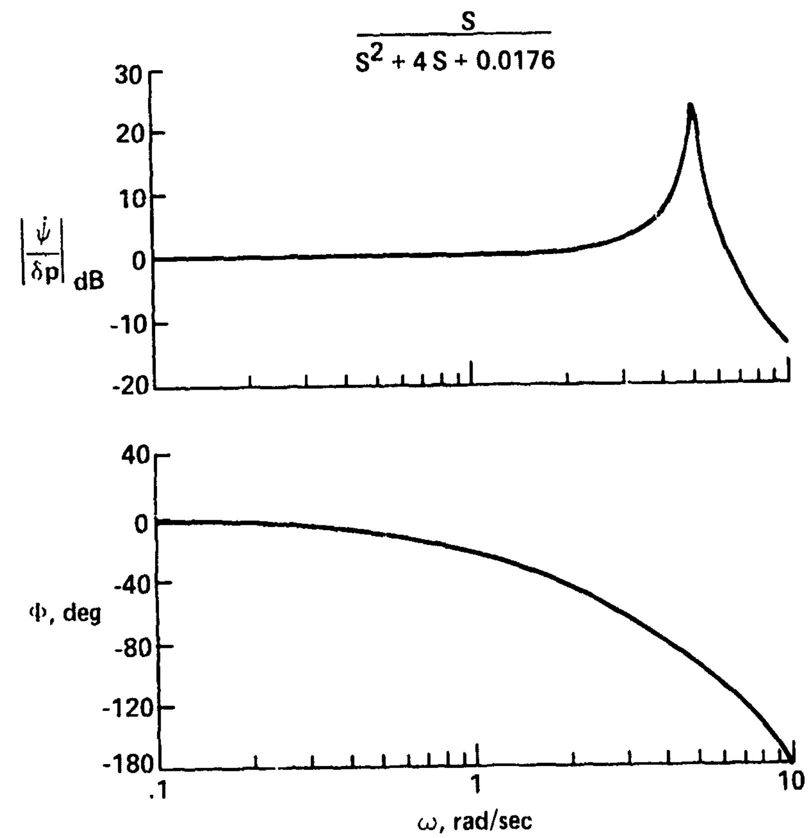


Figure J37.- Frequency response for closed loop transfer function with pilot model - configuration 37.

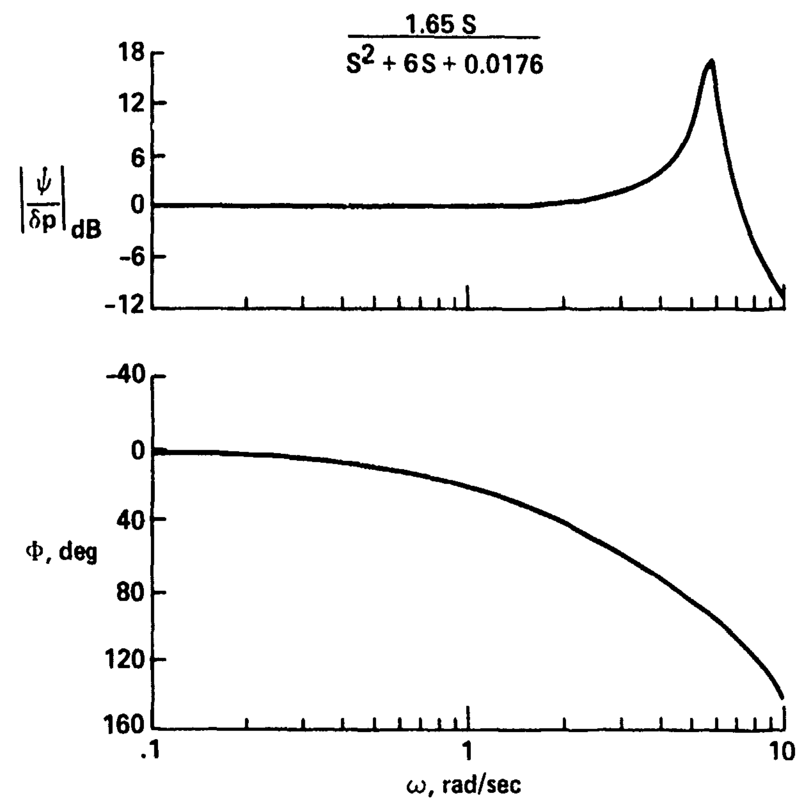


Figure J38.- Frequency response for closed loop transfer function with pilot model - configuration 39.

APPENDIX K

FIRE-CONTROL TASK PERFORMANCE DATA

Tables K-1 through K-5 list, respectively, the successful firing times, the mission outcome codes, the pilot reaction time, the circular error radius performance data, and the maximum yaw rate performance data for the air-to-air missile engagement task by pilot and test configuration.

TABLE K-1.- AIR-TO-AIR MISSILE ENGAGEMENT SUCCESSFUL FIRING TIMES

Test configuration	Successful-firing times						
	p1	p2	p3	p4	n	$\bar{x}$	sd
3	---	---	---	---	-	---	---
4	---	---	11.160	9.410	2	10.285	0.075
5	7.490	---	7.150	---	2	7.320	.170
6	8.550	---	---	---	1	8.550	0
7	---	---	---	---	-	---	---
8	---	---	7.010	---	1	7.010	0
9	---	---	---	---	-	---	---
10	---	---	7.490	---	1	7.490	0
11	---	---	---	---	-	---	---
12	---	---	7.780	9.980	2	8.880	1.100
13	---	---	---	9.790	1	9.790	0
14	---	---	---	---	-	---	---
15	7.680	---	8.100	9.980	3	8.587	1.000
16	---	---	7.920	---	1	7.920	0
17	---	---	---	---	-	---	---
18	---	---	7.970	---	1	7.970	0
19	---	---	8.930	6.820	2	7.875	1.055
20	---	---	4.800	9.220	2	7.010	2.210
21	---	---	10.890	11.230	2	11.060	.170
22	---	---	10.350	9.980	2	10.165	.185
23	9.600	---	7.650	8.450	3	8.567	0.800
24	---	---	7.380	---	1	7.380	0
25	---	---	---	9.600	1	9.600	0
26	12.640	---	---	---	1	12.640	0
27	---	---	---	7.200	1	7.200	0
28	---	---	---	9.410	1	9.410	0
29	8.930	10.370	---	8.450	3	9.250	0.816
30	8.350	---	5.940	6.430	3	6.907	1.040
31	---	---	---	---	-	---	---
32	---	---	---	---	-	---	---
33	---	---	---	11.230	1	11.230	0
34	---	---	---	7.300	1	7.300	0

TABLE K-1.- Concluded

Task configuration	Successful-firing times						
	p1	p2	p3	p4	n	$\bar{x}$	sd
37	---	---	7.290	---	1	7.290	0
38	8.540	---	8.550	7.780	3	8.290	0.361
39	---	---	9.760	---	1	9.760	0
40	---	---	---	7.580	1	7.580	0
51	---	---	7.380	6.050	2	6.715	0.665
52	---	---	---	9.020	1	9.020	0
53	---	---	---	---	-	---	---
54	---	---	---	---	-	---	---
56	---	---	---	---	-	---	---
57	---	---	---	9.600	1	9.600	0
58	---	---	---	8.640	1	8.640	0
Average	8.800	10.370	8.200	8.700			

TABLE K-2.- MISSION PERFORMANCE RESULTS FOR TASK 5 (TARGET ACQUISITION)

Test configuration	MOC				Frequency			
	p1	p2	p3	p4	S[1]	F[2]	I[3]	% Success
3	3	3	0	3	0	3	1	0
4	9	0	1	1	2	0	2	100.00
5	1	0	1	3	2	1	1	66.67
6	1	3	9	3	1	2	1	33.33
7	9	3	9	3	0	2	2	0
8	9	3	0	0	1	1	2	50.00
9	0	3	4	3	0	3	1	0
10	0	3	1	0	1	1	2	50.00
11	0	0	9	3	0	1	3	0
12	3	0	1	1	2	1	1	66.67
13	0	3	9	1	1	1	2	50.00
14	9	3	5	0	0	2	2	0
15	1	--	1	1	3	0	0	100.00
16	3	--	1	3	1	2	0	33.33
17	3	3	3	0	0	3	1	0
18	0	0	1	3	1	1	2	50.00
19	0	9	1	1	2	0	2	100.00
20	3	3	1	1	2	2	0	50.00
21	0	--	1	1	2	0	1	100.00
22	0	--	1	1	2	0	1	100.00
23	1	--	1	1	3	0	0	100.00
24	4	--	1	3	1	2	0	33.33
25	2	3	5	1	1	3	0	25.00
26	1	3	9	3	1	2	1	33.33
27	0	3	0	1	1	1	2	50.00
28	9	3	3	1	1	2	1	33.33
29	1	1	0	1	3	0	1	100.00
30	1	--	1	1	3	0	0	100.00
31	3	--	0	3	0	2	1	0
32	3	--	5	0	0	2	1	0
33	0	0	3	1	1	1	2	50.00
34	0	3	0	1	1	1	2	50.00
37	0	--	1	0	1	0	2	100.00
38	1	3	1	1	3	1	0	75.00
39	0	--	1	3	1	1	1	50.00
40	0	--	0	1	1	0	2	100.00
51	--	--	1	1	2	0	0	100.00
52	--	--	--	1	1	0	0	100.00
53	--	--	0	--	0	0	1	0
54	--	--	--	3	0	1	0	0
55	3	--	--	3	0	2	0	0

TABLE K-2.- Concluded

Test configuration	MOC				Frequency			
	p1	p2	p3	p4	S^1	F^2	I^3	% Success
57	--	--	0	1	1	0	1	100.00
58	--	--	--	1	1	0	0	100.00

[1]Pilot fires missile before 15 sec limit.

[2]Run ends because time limit was exceeded, altitude limit was exceeded, or aircraft crashed into the surrounding terrain.

[3]Run was incomplete due to simulation problems.

TABLE K-3.- PILOT REACTION TIMES (SEC) FOR TASK 5 (TASK ACQUISITION)

Test configuration	p1	p2	p3	p4	n	x	sd
3	6.483	1.482	---	1.532	3	3.166	2.345
4	4.563	---	2.283	2.303	3	3.049	1.070
5	3.883	---	3.273	1.482	3	2.879	1.019
6	2.602	.148	4.673	.812	3	2.696	1.577
7	3.903	4.412	4.493	1.962	4	3.693	1.024
8	3.633	2.203	3.883	---	3	3.239	.740
9	---	.048	3.863	.522	2	2.193	1.670
10	---	1.582	2.832	---	2	2.207	.625
11	---	---	2.823	3.363	2	3.093	.270
12	.433	---	2.642	2.303	3	1.793	.972
13	---	1.772	5.033	.332	3	2.379	1.966
14	3.142	.522	4.122	---	3	2.596	1.520
15	.148	---	1.572	2.593	2	2.082	.510
16	2.353	---	1.752	1.923	3	2.009	.252
17	2.923	2.193	5.233	---	3	3.449	1.296
18	---	---	4.563	1.772	2	3.168	1.395
19	---	.242	3.313	.722	3	1.426	1.348
20	4.223	.142	4.563	.722	4	2.413	1.994
21	---	---	2.013	.142	2	1.077	.935
22	---	---	2.193	.242	2	1.218	.975
23	1.202	---	2.153	1.103	3	1.486	.473
24	.043	---	1.163	1.393	3	.866	.590
25	1.482	1.873	1.113	1.722	4	1.548	.287
26	.802	3.503	2.373	2.303	4	2.245	.959
27	---	.142	---	2.063	2	1.102	.960
28	6.283	.433	4.412	.142	4	2.818	2.617
29	1.822	.722	---	.242	3	.929	.661
30	1.633	---	2.783	2.443	3	2.286	.482
31	.043	---	---	1.633	2	.838	.795
32	.722	---	2.642	---	2	1.683	.960
33	---	---	5.233	2.063	2	3.648	1.585
34	---	3.553	---	1.292	2	2.423	1.130
37	---	---	2.153	---	1	2.153	0
38	.238	2.113	1.433	2.063	3	1.869	.309
39	---	---	3.682	2.253	2	2.967	.715
40	---	---	---	.722	1	.722	0
51	---	---	2.283	1.722	2	2.003	.280
52	---	---	---	2.493	1	2.493	0
53	---	---	---	---	-	---	---
54	---	---	---	.332	1	.332	0
55	2.063	--	---	2.443	2	2.253	.190
57	---	---	---	.623	1	.623	0
58	---	---	---	.242	1	.242	0

TABLE K-4.- CIRCULAR ERROR RADIUS PERFORMANCE DATA (FT) FOR TASK 5 TARGET ACQUISITION

Configuration	Pilot				Average
	1	2	3	4	
3	18	14		20	17.3
4	8		8	6	7.3
5	6	4	10	8	7
6	10	8	6	20	11
7	8	4	6	4	5.5
8	6	10	8	6	7.5
9	6	10	8	6	7.5
10		4	6		5
11	18	6	4	10	9.5
12	12	18	6	12	12
13	28	10	6	8	13
14		14	14	22	12.5
15	6		2	6	4.66
16	20		4	8	10.6
17	8	4	8	10	7.5
18	8	6	8	10	8
19		12	8	6	8.66
20	14	8	8	10	10
21	12		10	10	10.6
22			8	8	8
23	6		4	12	7.3
24	14		14	8	12
25	6	4	6	10	6.5
26	22	4	20	8	13.5
27	18	8	8	4	9.5
28	12	10	2	4	7
29	4	18	26	4	13
30	16		4	22	10.5
31	34		8	8	16.5
32	34		12	4	16.6
33	10	4	6	12	8
34	12	4	12	12	10
35					
36					
37			6	6	6
38	4	2	6	8	5
39			6	14	10
40			16	9	8.86
51			18	4	11
52				8	8
53			6		6
54				4	4
55	8			2	5

TABLE K-4.- Concluded

Configuration	Pilot				Average
	1	2	3	4	
57			4	6	5
58				2	2
Average	13.3	7.9	8.8	13.1	8.86
Average with augmentation only					5.85

TABLE K-5.- YAW RATE PERFORMANCE DATA (DEG/SEC)
FOR TASK 5 TARGET ACQUISITION

Configuration	Pilot				Average
	1	2	3	4	
3	43.9	18.3		20.2	27.4
4	36.5		37*	18.9*	30.8
5	29.7*		25.9*	13.7	23.1
6	25.2*	12.8		17.8	18.6
7	23.4	14	9.9	11.7	23.1
8	31.8	13.5	24.9*		23.4
9	25.4	22	41	17.0	26.4
10		18.1	37*		27.5
11	32		39.7	20.6	30.7
12	35.6	9.8	35.1*	20.8*	27.6
13	20.5	14	17.7	15.4*	16.9
14	21.9	14.5		13.6	16.7
15	42*		28*	10.5*	26.8
16	38		40*	13	30.3
17	29.8	22	28		26.6
18	17.7		36*	21	24.9
19			32*	22.2*	27.1
20	38.2	18.6	29*	20.1*	26.4
21			29*	19.0*	24
22			31*	23.4*	33.1
23	45*		31*	23.4*	33.1
24	49		31*	20.0	33
25	30.6	24	35.1	22.4*	37.3
26	40.6*	28	26	26.1	30.15
27	21.5	25		27.7*	24.7
28	38.5	19.6	36.3	25.2*	29.9
29	31.7*	15.8*		17.5*	21.6
30	28.8*		28*	27*	27.9
31	35			13.4	24.2
32	32.4				32.4
33	27.8		26	24.3*	26
34	27.9	31		21.6*	26.8
35					
36					
37			28*		28
38	27.6*	13.6	35*	11.8*	22
39			36*	17.1	26.5
40				26.7*	26.7
51			35.2*	21.6*	28.4
52				13.4*	13.4
53					
54				33	33
55	37			14.7	25.9

TABLE K-5.- Concluded

Configuration	Pilot				Average
	1	2	3	4	
57				21*	21
58				23*	23
Average	32.2 33.8*	18.5 15.8*	31 31.9*	21.14 20.7*	25.7

*Successful target engagement.

REFERENCES

1. Harris, T. M.; and Beerman, D. A.: Impact of Flying Qualities on Mission Effectiveness for Helicopter Air Combat. Flight Systems, Inc., Newport Beach, Calif., NASA CR-166568, Feb. 1983.

2. Edenborough, H. K.: Control and Maneuver Requirements for Armed Helicopters. Bell Helicopter Company paper presented at the American Helicopter Society 20th Annual Meeting, May 13-15, 1964.

3. Dooley, L. W.: Handling Qualities Considerations for NOE Flight. Bell Helicopter Textron, paper No. 1041 presented at the 32nd AHS Forum, May 1976.

4. Tapscott, R. J.: Criteria for Control and Response Characteristics in Hovering and Low-Speed Flight. Aero/Space Engineering, June 1960, pp. 38-41.

5. Pegg, R. F.; and Connor, A. B.: Effects of Control-Response Characteristics on the Capability of a Helicopter for Use as a Gun Platform. NASA TN D-464, Sept. 1960.

6. Lynn, Robert R.: New Control Criteria for VTOL Aircraft. Aerospace Engineering, Aug. 1962, pp. 31-40.

7. Goldstein, K. W.: VTOL and VSTOL Handling Qualities Specification, An Overview of the Current Status. NASA CP-2219, April 1982.

8. Vinje, E. W.; and Miller, D. P.: Flight Simulator Experiments and Analyses in Support of Further Development of MIL-F-83300 - V/STOL Flying Qualities Specification. AFFDL-TR-73-34, June 1973.

9. Craig, S. J.; and Campbell, A.: Analysis of VTOL Handling Qualities Requirements (Part II). Systems Technology Incorporated, AFFDL-TR-67-179, Feb. 1979.

10. Gould, D. G.; and Daw, D. F.: A Flight Investigation of the Effects of Weathercock Stability on V/STOL Aircraft Directional Handling Qualities. National Research Council of Canada, Report No. LR-400, May 1964.

11. Smith, R. E.: Comparison of V/STOL Aircraft Directional Handling Qualities Criteria for Visual and Instrument Flight Using an Airborne Simulator. National Research Council of Canada, Report No. LR-465, Sept. 1966.

12. Doetsch, K. H.; and Gould, D. G.: A Flight Investigation of Lateral-Directional Handling Qualities for V/STOL Aircraft in Low Speed Maneuvering Flight. National Aeronautical Establishment, AFFDL-TR-69-41, Mar. 1970.

13. Chalk, C. R.; and Key, D. L.: Background Information and User Guide for MIL-F-83300 - Military Specification - Flying Qualities of Piloted V/STOL Aircraft. Cornell Aeronautical Laboratory, AFFDL-TR-70-88, Mar. 1971.

14. Anon: Military Specification-Flying Qualities of Piloted V/STOL Aircraft. MIL-F-83300, Dec. 31, 1970.

15. Key, D. L.: The Status of Military Helicopter Handling-Qualities Criteria. AVRADCOM paper presented at AGARD FMP Specialist Meeting on "Criteria for Handling Qualities of Military Aircraft," Fort Worth, Tex., Apr. 1982.

16. Anon: Military Specification-Helicopter Flying and Ground Handling Qualities; General Requirements For. MIL-H-8501A, Sept. 7, 1961.

17. Seckel, E.: Stability and Control of Airplanes and Helicopters. Academic Press, Inc., New York, 1964.

18. Heffley, R. K.: A Compilation and Analysis of Helicopter Handling Qualities Data, Volume One: Data Compilation. NASA CR-3144, Aug. 1979.

19. Anon: Aircrew Training Manual - Attack Helicopter. Training Circular No. 1-136, United States Army Aviation Center, Jan. 1981.

20. Pitt, D. M.: Advanced Scout Helicopter Flying Qualities Requirements, How Realistic Are They? AVRADCOM, paper No. 79-28 presented at the 35th AHS Forum, May 1979.

21. Carico, D.; and Blanken, C. L.: Fixed-Base Simulator Investigation of Display/SCAS Requirements for Army Helicopter Low-Speed Tasks. AVRADCOM paper No. A-83-39-60-4000 presented at the 39th Annual AHS Forum, May 9-11, 1983.

22. Hoh, R. H.; and Ashkenas, I. L.: Handling Quality and Display Requirements for Low Speed and Hover in Reduced Flight Visibility. Systems Technology, Inc., paper No. 79-29 presented at the 35th Annual AHS Forum, May 1979.

23. Lebacqz, J. V.; and Aiken, E. W.: A Flight Investigation of Control, Display, and Guidance Requirements for Decelerating Descending VTOL Instrument Transitions Using the X-22A Variable Stability Aircraft. CALSPAN Report No. AK-5336-F-1, Sept. 1975.

24. Hoh, R. H.: Bring Cohesion to Handling-Qualities Engineering. Astronautics & Aeronautics, June 1983, pp. 64-69.

25. Aiken, E. W.: A Mathematical Representation of an Advanced Helicopter for Piloted Simulator Investigations of Control System and Display Variations. AVRADCOM TM 80-A-2, June 1980.

26. Talbot, P. D.; Decker, W. A.; Tinling, B. E.; and Chen, R. T.: A Mathematical Model of a Single Main Rotor Helicopter for Piloted Simulation. NASA TM-84281, Sept. 1982.

27. Blake, Bruce B.; and Hodder, D.: Wind Tunnel Investigation into the Directional Control Characteristics of an OH-58 Helicopter. Applied Technology Laboratory, USAAVRADCOM-TR-83-D-18, June 1984.

28. Marshall, R.; Nagata, J.; and Carpenter, R.: OH-58C Vertical Fin Blockage Evaluation. United States Army Aviation Engineering Flight Activity Project No. 83-03, Mar. 1983.

29. Aiken, E. W.; and Blanken, C. L.: Piloted Simulation of the YAH-64 Backup Control System Engagement. USAAVRADCOM TR-81-A-11, July 1981.

30. Aiken, E. W.; and Merrill, R. K.: Results of a Simulator Investigation of Control System and Display Variations, paper No. 80-28 for the 36th Annual American Helicopter Society Forum, May 1980.

31. Anon: Military Specification-Flying Qualities of Piloted Airplanes. MIL-F-8785C, Nov. 5, 1980.

32. Cooper, G. E.; and Harper, R. P.: The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. NASA TN D-5253, Apr. 1969.

33. Mudd, S. A.: The Treatment of Handling-Qualities Rating Data. Human Factors, Vol. II(4), 1969, pp. 321-330.

34. Merritt, E. S.; and Cioffi, C. C.: OH-58 Tail Rotor Control Power. U.S. Army Aviation Digest, Mar. 1982, pp. 3-10.

35. Hewetson, M. J. T.: Tail Rotor Breakway. Aerospace Safety, Oct. 1980, pp. 7-9.

36. Hoh, R. H.; Myers, T. T.; Ashkenas, I. L.; Ringland, R. F.; and Craig, S. J.: Development of Handling Quality Criteria for Aircraft with Independent Control of Degrees of Freedom. Systems Technology, Inc., AFWAL-TR-3027, Apr. 1981.

37. Shah, S. C.; Walker, R. A.; and Gregory, C. Z.: Matrix-X User's Guide, V4.0. Integrated Systems, Inc., Palo Alto, Calif., 1985.

NASA
National Aeronautics and Space Administration

F

AD-A185 874

1. Report No.		3. Recipient's Catalog No.
NASA TM 86755 USAAVSCOM TR 85-A-11		

4. Title and Subtitle

A Simulation Investigation of Scout/Attack Helicopter Directional Control Requirements for Hover and Low-Speed Tasks

5. Report Date

March 1987

6. Performing Organization Code

7. Author(s)

Courtland C. Bivens* and Joseph G. Guercio

8. Performing Organization Report No.

A-85257

10. Work Unit No.

992-21-01-90-01

9. Performing Organization Name and Address

Ames Research Center, Moffett Field, CA 94035 and
*Aeroflightdynamics Directorate, U.S. Army Aviation Research and Technology Activity, Ames Research Center, Moffett Field, CA 94035-1099

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration, Washington, DC 20546-0001 and U.S. Army Aviation Systems Command, St. Louis, MO 63120-1798

13. Type of Report and Period Covered

Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes

Point of Contact: Courtland C. Bivens, Ames Research Center, MS 210-7, Moffett Field, CA 94035, (415)694-5836 or FTS 464-5836

16. Abstract

A piloted simulator experiment was conducted to investigate directional axis handling qualities requirements for low speed (≤40 knots) and hover tasks performed by a Scout/Attack helicopter. Included in the investigation were the directional characteristics of various candidate light helicopter family configurations. Also, the experiment focused on conventional single main/tail rotor configurations of the OH-58 series aircraft, where the first-order yaw-axis dynamic effects that contributed to the loss of tail rotor control were modeled. Five pilots flew 22 configurations under various wind conditions. Cooper-Harper handling quality ratings were used as the primary measure of merit of each configuration. The results of the experiment indicate that rotorcraft configurations with high directional gust sensitivity require greater minimum yaw damping to maintain satisfactory handling qualities during nap-of-the-Earth flying tasks. It was also determined that both yaw damping and control response are critical handling qualities parameters in performing the air-to-air target acquisition and tracking task. Finally, the lack of substantial yaw damping and larger values of gust sensitivity increased the possibility of loss of directional control at low airspeeds for the single main/tail rotor configurations.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Flight simulation Helicopter handling qualities Directional control	Unclassified - Unlimited Subject category - 08

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	297	A13

NASA FORM 1626 OCT 86

For sale by the National Technical Information Service, Springfield, Virginia 22161